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Title:

Do you see what I see? The difference between dog and human visual perception may affect the outcome of experiments

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Abstract

The visual sense of dogs is in many aspects different than that of humans. Unfortunately, authors do not explicitly take into consideration dog-human differences in visual perception when designing their experiments. With an image manipulation program we altered stationary images, according to the present knowledge about dog-vision. Besides the effect of dogs' dichromatic vision, the software shows the effect of the lower visual acuity and brightness discrimination, too. Fifty adult humans were tested with pictures showing a female experimenter pointing, gazing or glancing to the left or right side. Half of the pictures were shown after they were altered to a setting that approximated dog vision. Participants had difficulty to find out the direction of glancing when the pictures were in dog-vision mode. Glances in dog-vision setting were followed less correctly and with a slower response time than other cues. Our results are the first that show the visual performance of humans under circumstances that model how dogs' weaker vision would affect their responses in an ethological experiment. We urge researchers to take into consideration the differences between perceptual abilities of dogs and humans, by developing visual stimuli that fit more appropriately to dogs' visual capabilities.
Keywords: dog; ethology; human; visual perception

1. Introduction

The interest for dogs as subjects in ethological experiments has steadily grown in the last two decades. A large number of empirical and theoretical studies have been written about the mechanisms and evolutionary processes involved in the socio-cognitive capacities of dogs (e.g. see for a review Miklósi and Topál, 2013). A key feature of the aforementioned research was the implementation of test protocols widely used in comparative psychology, or specifically created for testing dog behavior. A vast majority of these methods involve visual tasks (see exceptions of olfactory (Polgár et al., 2015), and acoustic tasks (Pongrácz et al., 2014)). Although many experiments require dogs to observe large moving objects/actors (such as humans (Pongrácz et al., 2012), other dogs (Pongrácz et al., 2008), objects (Abdai et al., 2015), life-size projected presentations (Péter et al., 2013), still many of the experiments conducted on dogs are designed to test abilities that require recognizing or making distinctions between fine details. Such experiments include (but are not restricted to) object permanence tasks (e.g. Collier-Baker et al., 2004; Fiset et al., 2006; Gagnon and Doré, 1992), pointing tasks (e.g. McKinley and Sambrook 2000; Soproni et al. 2001), tasks regarding gaze following (e.g.: Hare and Tomasello, 1999; Kaminski, Bräuer, et al., 2009), facial discrimination tasks (e.g.: Adachi et al., 2007; Nagasawa et al., 2011), studies of attention (Siniscalchi et al., 2010), studies with touch-screen (Range et al., 2008), or any other tasks involving visual stimulus presentation (e.g. Kaminski, et al., 2009; Pongrácz et al., 2003). When opting for protocols, researchers understandably chose methods that were already employed successfully in comparative research on humans and/or primates. It is also obvious (although never explicitly expressed) that the tests were designed with the human visual perception in mind. However, while the visual capacity is rather similar in humans and their closest relatives (great apes and old world monkeys (Jacobs, 1996)), the situation is drastically different when the chosen subjects are dogs.

The visual capacity of dogs is similar to the vision of closely related predatory species, such as different fox species (Island gray fox (*Urocyon littoralis*), red fox (*Vulpes vulpes*), and Arctic fox (*Alopex lagopus) – Jacobs et al., 1993)* and wolves (*Canis lupus* - Miller and Murphy, 1995). Dog vision was adapted for functioning in a wide range of circumstances (i.e. various light conditions), with possible emphasis on motion detection instead of discrimination for static details, and a higher suitability for processing stimuli that are relatively far from the animal. The anatomical changes of the skull in particular dog breeds (McGreevy et al., 2004), as well as the assumed force of selection towards better communicative abilities with humans resulted in between-dog differences in the shape and size of the visual field, which may contributed in such between-breed differences in vision-based dog behavior as the different performance in following human visual cues in a two-way choice test (Gácsi et al., 2009). There are somewhat contradicting empirical results on the relative importance of vision and olfaction during search-related tasks in dogs. While for example Gazit and Terkel (2003) found that working dogs rely more on their sense of smell than on their vision, Polgár et al., (2015) showed that even well-trained searching dogs fail to use their nose when they are presented with a simple, but unusual task consisting of finding their nearby sitting owner by following only olfactory cues. While Gazit and Terkel (2003) argued that dogs' vision is relatively useless in static tasks (as it evolved mostly to notice and follow movement), Polgár et al. (2015) mentioned that companion dogs in the anthropogenic niche are provided usually by visual cues by the humans, therefore they may learn to rely more on their eyes than their nose. Comparatively to their sense of smell and hearing, dogs' sense of vision is considered weaker than humans'. An overview of the differences between the visual perception of dogs and humans follows in the next paragraphs, however at this time we will only focus on the differences that can be visualized with the help of digital image processing: color perception, brightness discrimination and visual acuity. The visual perception of both humans and dogs is characterized by additional attributes such as the sensitivity to motion, sensitivity to flickering lights, etc. It is worth to note that dogs (similarly to cats, for example) are sensitive to much higher flicker rates than humans are, which also warrants for attention in case of using moving presentations on TV or computer screens (Coile et al., 1989). A review by Miller and Murphy (1995) provides further reading about dogs' vision. It is important to mention that since the in-depth study of Miller and Murphy there is no more recent, similarly thorough review or empirical study was written about the details of dog vision, with only a very few exceptions that we discuss later in details (particularly the study of Pretterer et al. (2004) on brightness-discrimination).

We start by discussing color perception. It is known that dogs have a dichromatic color vision (Jacobs et al., 1993; Neitz et al., 1989). This means that dogs have two types of light sensitive photo pigments in the cone cells of their retina. Humans on the other hand have three different types of photo pigments; therefore they can distinguish more hues than dogs can. The three photo pigments in humans are often called red, green and blue, according to the apparent hue of the wavelength of light they are most sensitive to. The two photo pigments of dogs, based on their sensitivity range, are similar to the human green and blue pigments. According to this, dogs' color vision should be similar to that of a person suffering from deuteranopia (a type of red-green colorblindness), in that they will confuse colors (or spectra) that are readily discriminable to trichromats. For instance, colors that we see as greenish-blue may be indistinguishable from achromatic (white or gray).

Next we compare the brightness discrimination in dogs and humans. Brightness discrimination is the ability to differentiate between different shades. It is measured by determining the smallest discernible difference in brightness between two stimuli. It is expressed as the ratio of the intensity of the two surfaces (Weber fraction). The Weber fraction for humans is 0.11 (Griebel and Schmid, 1997) whereas the Weber fraction for dogs is 0.22 (Pretterer et al., 2004). Based on these studies we can state that the brightness discrimination of dogs is about two times worse than that of humans.

The third difference in visual perception between dogs and humans is acuity. Visual acuity is a measure of the spatial resolution of the visual system. It is often measured in cycles per degree (CPD), which is the number of cycles of a grating (one dark and one light band) subtended at the eye per degree. The maximum visual acuity is equal to the highest CPD value where the grating is still perceived as being comprised of separate bands. The maximum visual acuity of the human eye is around 50 CPD (Russ, 2006) and 60 CPD (Campbell and Green, 1965). The measurements of dogs' visual acuity vary between 7.5-9 CPD (Murphy et al., 1997) and 11.6 CPD (Odom et al., 1983). According to these measurements dogs' visual acuity is four to eight times worse than that of humans.

Despite such evidence regarding the differences between human and dog vision, there are only very few exceptions, where the authors made some attempts to design experiments according to the specificities of dog vision. Range et al (2008) tested dogs in an experiment where the subjects had to learn to categorize pictures according to their content (‘dogs’ vs. ‘landscapes’) with the help of a touch-screen device. Here the authors mention that they acknowledged the difference between dogs’ and humans’ color vison, however it has been already proven that this kind of task does not require color vision (e.g. in pigeons: Aust and Huber, 2001). Otherwise, it is worrisome to an extent that ethologists seemingly do not take it in consideration that dogs might see differently the experimental stimuli than the humans do, as any unaccounted difference between the visual perception of dogs and humans could result in dogs perceiving the visual stimuli in a way not anticipated by the researchers. This consequently may lead to puzzling results or to a misinterpretation of dogs’ behavior in the tests. For example, depending on the study in question, dogs were found to be more or less successful in following human glances (McKinley and Sambrook, 2000; Soproni et al., 2001), meanwhile they were much more effective in following the more evident arm signals (e.g. Lakatos et al., 2008; Pongrácz et al., 2013a; Soproni et al., 2002). Another widely used testing paradigm is based on dogs’ initial choice between two amounts of small food pellets (1 vs 8) (Prato-Previde et al., 2008). Although the difference in this quantity discrimination task seems obvious and decisive for anyone, there is evidence (Marshall-Pescini, 2011; Ward and Smuts, 2007,) that a considerable number of dogs chose the smaller amount of food instead of the larger. Considering the weaker acuity of dog vision, the ambiguous results in both the glance following and the quantity discrimination tests could be explained hypothetically on the basis of inadequate visual performance.

By taking into account the above listed differences in the visual perception of dogs and humans, researchers theoretically should design experiments by selecting more appropriate visual stimuli for their subjects. However, seeing the effects of these differences directly on the actual stimuli or on the experimental environment could be even more helpful in the design phase of the experiment. However, simulating dog-vision for humans would be very difficult even if we would have a much more detailed knowledge about the specific parameters of the visual perception of dogs – because this would require (1) a very sophisticated technology of visual image presentation; and (2) even if the technology would be given, we could not be sure whether canine and human brains process similarly the visual sensation.

To begin with, an image processing tool that could approximately visualize the main differences in the visual perception of the two species would provide a good idea for the experimenter to model whether there could be problems with a visual task when dogs would be the subjects. There are devices that are already available for this purpose. Some of these are plug-ins for image processing programs (e.g., Color-Blindness Simulators by L. Petrich), therefore in order to use them one needs to install these programs first. Others tools are more interactive and run on smartphones (e.g. ‘Dog vision’ by NGHS). However these tools are only for showing the differences in color perception, they do not make it possible to demonstrate the effect of decreased visual acuity and the decreased brightness discrimination, which are important contributors to the differences in visual perception (see e.g. Scholtyssek et al., 2015).

In this study we tested a new, freely available web based image processing tool (http://dog-vision.com; copyright A. P.) that overcomes some of the limitations of the presently available solutions. This tool enables the users to observe the effects of dichromacy, decreased brightness discrimination and decreased visual acuity, separately or arbitrarily combined (see further details in the Appendices). In our experiment we tested human subjects with pictures in their original and altered form. We used a modified version of the two-object choice test with human pointing (see Soproni et al., 2001), where subjects had to decide which side was indicated by the depicted human on the image. Three types of directional indication were presented in both the human and dog-vision setting: point with extended arm, head-turn and glance. Our main question was whether the accuracy and speed of the subjects' answers were affected by the visual setting of the presentations – we hypothesized that the more subtle is the directional information (i.e. point with arm vs glance) the stronger will be the drop in the subjects' performance.

2. Materials and methods

2.1 Participants

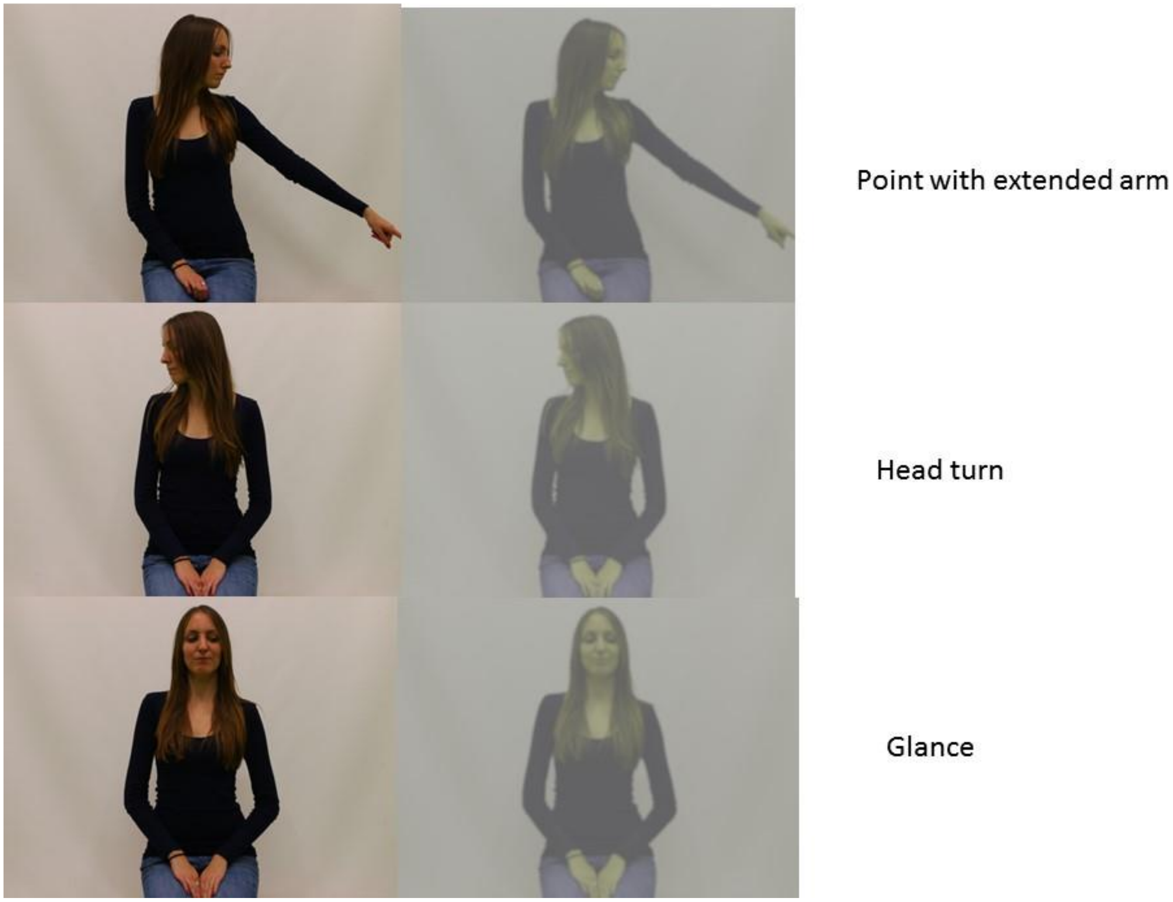
Fifty adults participated in the study. Based on the literature, in two-way choice experiments similar to the present study the average group size falls between 15-30 individuals (i.e. Pongrácz et al., 2013a), therefore the N=50 can be considered as an effective sample size. Half of the participants were men (average age 26, minimum 19, maximum 43 years), the other half were women (average age 24, minimum 19, maximum 36 years). Participation was voluntary; subjects were recruited through advertising of the tests at the University campus site and through personal acquaintances. We did not have specific requirements for the participants, with the exception that if they needed glasses/contact lenses, we requested them to wear these aids during the test. The proportion of participants who had glasses/contact lenses did not differ between the genders (Fisher Exact test, R=0.88; P=0.78). Written informed consent was obtained from all subjects a priori to the test. The experimental protocol has been reviewed and accepted by the United Ethical Review Committee for Research in Psychology (EPKEB Ref No. 55/2015).

2.2 Preparation of the test photographs

Test subjects were provided with photographs depicting a young woman who performed the directional signalling. All pictures showed the same person (V.U.) in front of a light beige colored textile sheet. A set of exemplars can be seen on Figure 1. Photographs were taken in large enough quantity that we could use five different pictures of each directional signalling type to both sides (left and right). No digital mirroring or other editing was performed on the pictures, with the exception of copying the full set of chosen experimental picture material to dog-vision setting.

It is important to emphasize that due to the differences in the sensitivity of the human eye and the imaging sensors and due to the limitations in the color reproduction capabilities of the computer screens no image processing tool could show exactly what dogs can or cannot perceive. However, we can assume that imaging and image reproducing devices have been tuned to match the sensitivity of the human eye. This simplification enables us to simulate the differences of color perception between dogs and humans with the help of digital images only by taking into account the differences between the sensitivity of the human and the canine photoreceptor system. The exact method how the image processing tool (http://dog-vision.com; copyright A. P.) works can be found in the Appendices.

Figure 1: Three pairs of pictures from the original presentation. Photographs in the first column are in human-vision setting, while the photographs in the second column were altered to dog-vision setting by the image processing tool (http://dog-vision.com). Each pair of photographs shows one particular type of directional signal (see description on the right).



2.3 Experimental process

Tests were conducted at the Department of Ethology, where the subjects were tested one by one with the assistance of the experimenter (V.U.) in a quiet, semi-dark room. Participants were instructed about the basic circumstances of the experiment, without explicit a-priori information about the types of directional signals they will see on the pictures. Test pictures were presented by and the participants' answers were recorded with the OpenSesame 2.9.4 software. Test pictures were shown on a full-HD computer screen of 1920x1080 pixels resolution. Participants watched the presentations 0.6m away from the screen. The experimenter's photograph was 0.24 m tall on the screen, resulting in a 0.13m apparent size from the viewer's distance. This means that our presentation resembled to a real scenario where the experimenter signals approximately

2.5m away from the subject – a distance that is routinely used in pointing experiments (e.g. Hegedüs et al., 2013; Pongrácz et al., 2013b; Soproni et al., 2001).

Each subject viewed an individually assembled slide show consisting of 80 photographs. Each photograph showed the experimenter, presenting one of three possible directional signals: point with extended arm (EA), look to one side by turning her head (HT), glance to one side while facing ahead (GL); and also a fourth type, dubbed as 'no directional information' or look ahead (LA). The randomly inserted LA pictures were used as a buffer against possible fast learning of directional cues by the participants. From each signal type, equal amount of left and right versions were presented (with a double amount of LA pictures). Additionally, half of the pictures were presented in human-vision and the other half in dog-vision setting. We used five versions of each picture type, and the same exact picture was used only once within the vision-settings. Therefore the final picture count was 4 (directional signal type) x 2 (side) x 2 (vision setting type) x 5 = 80. Pictures were presented in a semi-random order with two restrictions: the first two presentations were always in human-vision setting and picturing directional signals other than LA; and the same side was indicated maximum twice in a row.

At the beginning each subject saw the same instruction on the screen:

"On which side is the ball?

You can answer by pressing the 'left' or 'right' arrow key.

Decide quickly, you have only 3s to choose.

Put your fingers on the arrow keys please, and press any of them to start!"

During the test a new picture emerged every time the subject pressed one of the arrow keys, or after 3s was elapsed. The software generated a .csv file from the answers, recording the correctness of choice and the response time. In case of lack of answer within 3s an automatic incorrect answer was recorded. Obviously, in case of the LA pictures neither left or right was a correct response – in this case the program pre-defined an arbitrary correct-incorrect distribution of answers.

2.4 Statistical analyses

We performed Generalized Linear Mixed Models analysis on the number of correct answers. We used the gender of the participants (male vs female), the type of the directional signal (EA, HT or GL), and the type of the presentation (human or dog-vision) as Fixed effects and the ID of the individuals as Random factor. The responses to LA pictures were not included in the analysis. Besides the main effects, we analyzed the 2-way interactions of the above mentioned three fixed effects. The normality of our data was analyzed by the visual examination of the QQ plots of residuals. To obtain the simplest model that sufficiently explains our data, we applied backward elimination model selection excluding interactions with the highest p-value step-by-step, till we reached effects with lower than 0.05 p values. In the following we report the obtained final models only. Post-hoc tests were performed as pairwise comparisons of the levels of the significant effects and controlled for multiple comparisons with Sequential Sidak method. These corrected p-values are reported in all post-hoc results. These statistical analyses were performed by the IBM SPSS Statistics 22.0 software.

To analyze the Response times (as these can be censored from both sides) we applied Cox Mixed-effects regression model (R (R Core Team, 2016) coxme package) (Therneau, 2015) with the subject identity as random factor. To find the best model we used forward approach, and included the main effects and interactions step-by-step to increase the complexity and tested the log-likelihood change between models. If the inclusion of an effect didn't result in significant change, we removed it from the model. We tested the same effects as in the case of the correct choices (see above). Subject gender had no significant effect, thus we left it out from the final model, which in this way contained the type of directional signal and type of presentation as main effects and their interaction.

3. Results

In the case of the number of correct answers, the model showed a significant effect (F(9, 290)=9.62; p<0.001). As all the fixed factors appeared in the significant 2-way interactions, we did not analyze the main effects separately. There was a significant interaction between the type of presentation and type of directional signal (F(2, 290)=4.35; p=0.014), where according to the post hoc test, participants showed a weaker performance in case of GL when it was presented in dog-vision setting. Furthermore, when the directional signals were presented in the dog-vision setting, participants showed significantly better performance in case of EA and HT than pictures showing GL (Figure 2). We found also a significant interaction between the gender of participants and the type of presentation (F(1, 290)=4.23; p=0.041). According to the post hoc analysis, men performed poorer in the case of presentations in the dog-vision setting (Figure 3). Gender of participants had a significant interaction with the type of directional signals as well (F(2, 290)=3.44; p=0.034). According to the post hoc analysis, men showed better performance in the case of HT than GL. Women performed best in the case of EA, and they showed the weakest performance also in the case of GL. The success of women in the case of HT was between EA and GL.

Figure 2. Number of correct answers in case of three types of directional signals, presented in human and dog vision setting (*N*=50 participants). Bars represent the number of correct answers in the case of different directional signals and type of presentation. Different letters inside the bars show significant differences within a presentation type (capitals: human vision; lower case: dog vision). Generalized Linear Mixed Modell, asterisk indicates significant difference within a directional signal type. * P<0.05

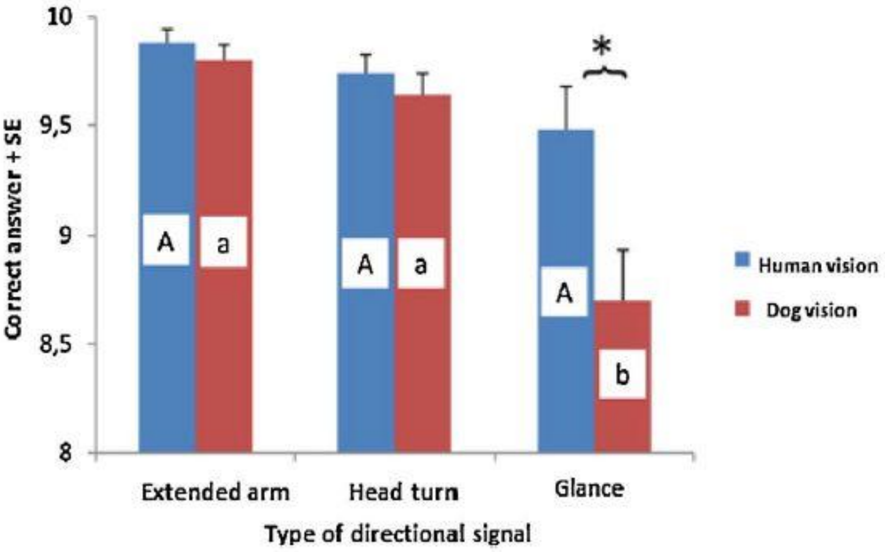
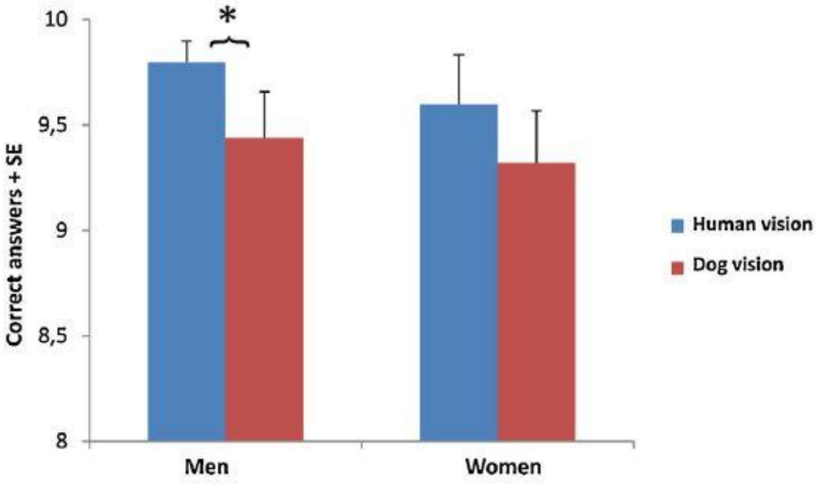


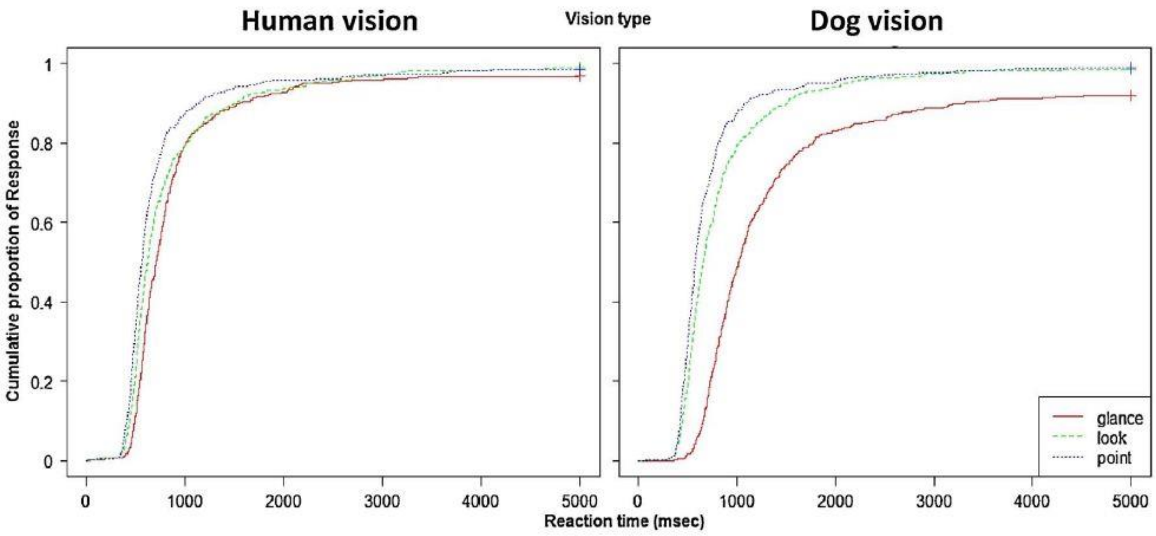
Figure 3. Number of correct answers given by male (*N*=25) and female (*N*=25) subjects. Bars represent the number of correct answers in the case of male and female participants, in different types of visual presentation. Generalized Linear Mixed Modell, asterisk indicates significant difference between the presentation types. * P<0.05



The Cox model proved to be significant in the case of response time, including an interaction between the type of presentation and the type of directional signal ($\chi2(2)=67.802$; $p<0.001$), suggesting a strong effect of dog vision in the case of GL presentation type only. The result show that compared to human vision, there was no significant difference in dog vision between the pointing and looking ($\exp(\beta)=0.975$; se=0.09; Z=-0.28; p=0.78), while the presentation of gazing in dog vision lowered the chance of quicker response by 50% ($\exp(\beta)= 0.51$; se=0.09; Z=-7.30; $p<0.001$) (Figure 4).

Figure 4. The cumulative proportion of responses compared between presentation and directional signal types (*N*=50 participants). The different lines represent the type of

directional signal. The course of the lines show the probability of response occurrence changing over time. The steeper the line rise the higher probability of quicker response it shows. (Cox Mixed-effects regression model, significant interaction between type of signal and type of presentation P<0.001).



4. Discussion

In our experiment human participants had to decide whether a young woman indicates the left or right direction with either her extended arm, head turning or glance. Half of the presentations appeared as a human would see them, however, the other half were altered to a new setting, where the hypothesized color-range, brightness and resolution arrangements were created according to the values drawn from the existing literature about dog-vision. The results showed that subjects could follow any of the directional signals in human perception mode and in the case of points with arm and head turns in dog-vision setting. However, in case of glancing, participants performed significantly worse when the presentation mimicked dogs' visual perception, and glances were the hardest to follow from among the directional signals presented in dog-vision setting. Interestingly, participants' gender also affected the performance, men in general performed poorer in dog-vision than in human vision setting. This finding is parallel with earlier results where men's performance was weaker in tasks where reflexive shifts of attention to gazed-at directions have been tested for, and, in general, when the two genders' performance was compared in following symbolic directional cues (Bayliss et al., 2004). Response time in our study also indicated how difficult it was to decipher glancing when pictures were altered to an approximate dog-vision. Participants responded slower to glances than to the other two directional signals.

In this paper we introduced a new image manipulation tool that attempts to display images after a complex alteration procedure, providing an approximation of dogs' visual sensations. Our hypothesis was that the generally weaker visual perception of dogs would result in lower performance in such tasks where the important details are relatively fine. The performance of the human participants proved that if the otherwise well visible glances were deteriorated with the image manipulating program towards the visual parameters that are closer to the level as a dog would probably perceive them, humans followed them with less success and slower than other (more robust) visual cues. Although the collected data are indirect, because they are based on human participants' responses rather than on dogs', our results warrant that some visual tasks for dogs may lie beyond (or on the threshold) of the capacity of canine visual perception.

Slower responses are especially important in the case of difficulties with making a decision. Although it was not explicitly tested on dogs in a two-way choice situation with human pointing gestures, we have a good indication that dogs may decide in a split second which side to choose in similar situations. In an experiment where dogs had to find a hidden target based on a hiding event projected on a screen, Péter et al. (2013) found that dogs performed more successfully if they were actually looking at the projected human assistant in the very moment he placed the target to a particular location. In any other case dogs chose randomly. In the case of experiments where dogs have to decide upon observing minor details and differences between gestures (Soproni et al., 2001), amounts (Prato-Previde et al., 2008) or presentations (Bálint et al., 2015), the shortest hesitation can result in opting for alternative mechanisms in choice decisions. Dogs may follow simple rules such as 'win-stay' or they may develop side bias when the directional cues are ambiguous (Bálint et al. 2015). Szetei et al. (2003) found that in the presence of a human experimenter, dogs do not rely on their sense of smell in a food-searching task, and even if the experimenter did not provide any directional signal, dogs chose randomly instead of following their noses. This situation may indicate a case when the directional cue is weakly visible for a dog, causing weaker choice performance.

Our pictures showed the human experimenter like she would cueing the subjects from a distance of 2.5 m. One could argue that in reality humans would use subtle signals like glancing with the eye from a closer distance. No doubt, both humans and dogs would have a greater chance to follow directional glances given from shorter distance – however, the above mentioned signaling distance is routinely used in such experiments where dogs are expected to make correct decisions in two-way choice tests (e.g. Soproni et al., 2001, 2002; Hegedüs et al., 2013). Dogs are able to choose correctly after receiving robust signals (like point with arm) from such distance – in congruence with our present results, where human participants did not have a problem following arm signals and head turns in dog vision setting either. However, when dogs are intended to be tested with more subtle cues, one should preferably opt for much shorter viewing distances.

Although hard evidence is mostly lacking, it is suggested that dogs' capacity to detect motion is better than humans' (Miller and Murphy, 1995). One could argue that when experimenters direct dogs with glancing, the cue is not static as in the still pictures in this study, but the experimenter's eyes also move to the indicated direction. However, Soproni et al. (2002) found that in an experiment where dogs had to choose between the targets based on a human's pointing gestures, the direction of the moving cue itself did not affect the number of correct responses. Although dogs proved to be sensitive to the attentive focus of a human (Virányi et al., 2004), it is unknown whether the motion component of a glancing eye would be enough for them to make a correct decision about the indicated side. At the same time, there are numerous testing conditions where dogs have to make a decision upon static visual presentations of finer details, such as the differentiation between amounts (Ward and Smuts, 2007) or facial expressions of depicted humans (Nagasawa et al., 2011). In these cases the motion component is surely missing, therefore the differences between the visual capacity of dogs and humans may represent a problem.

An advantage of our picture manipulation method is that it adjusts three crucial factors of visual perception (color, brightness, acuity) together. Techniques that intend to test visual capacity of non-human animal species many times concentrate on a single factor only, typically on color vision. As it turned out, for example in marine mammals, adjusting only the color of the presentations may lead to paradox results, claiming that animals with only one type of cone cell in their retina may be able to distinguish among colors (e.g. Griebel and Schmid, 1992, 2002). While in other experiments when not only the color, but also brightness was under control, it turned out that (at least harbor seals) are completely color blind (Scholtyssek et al., 2015). The picture manipulating method used for our study here creates such visual presentations that diverge from the ones humans used to see in three important parameters (with the exception of the dynamic components) that differentiates canine and human vision.

Obviously, the results of this experiment do not suggest that ethologists employed erroneous or insufficient methods when they were testing dogs in visual discrimination tasks in the past. The long list of mostly positive results proves that dogs perform in these experiments usually on acceptable levels for drawing conclusions based on the average performance of the groups. However, what is usually not reported in the results, but scientists face as an everyday nuisance –high drop-out rate of subjects due to lack of surpassing preliminary criteria for the tests; or a high standard deviation value in some of the experimental groups – these may be the results of poor experimental design due to the visually challenging presentations for dogs. Although inadequate motivation level of the subjects, problems with the stressful test environment, visual impairments such as myopia (e.g. Murphy et al. 1992) etc. may also influence the response of dogs during testing, a task that is at the verge of visual capacity of dogs may also be the key to suboptimal performance. In the case of the latter, other factors such as light conditions, distance from the target, etc., may also decide the actual outcome of an experiment.

We are convinced that taking into account the differences in perception will lead to experimental designs that have a higher rate of success and that yield unambiguous results. This means more efficient conducting of studies and less flawed designs that would otherwise waste time by necessitating a rerun of the tests. Our study provided some insight to a scenario where humans had to perform in a visual task where images were manipulated in a complex way, using color, brightness and resolution values based on our knowledge about canine vision. The weaker performance of our subjects in case of manipulated images should urge experimenters to do more basic research on the specific requirements of proper visual presentations for canine subjects.

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7. Appendices

7.1 Visualizing the differences in color perception

Digital images are composed of picture elements (pixels) which are arranged in a two dimensional matrix. Each pixel stores values that represent the brightness and color at the pixel’s position. In color images, pixels store three values: Red, Green and Blue (RGB image). Each of these values represents the brightness of the given color at the pixel’s position. The three color values can be regarded as corresponding to the level of excitation of the three photo pigment types in the human eye. Dogs could be regarded as lacking the red photo pigment, but this does not mean that they are unable to detect wavelengths that humans recognize as red. This is because the wavelengths that would be absorbed by the red photo pigment are also absorbed by the green photo pigment, albeit with a lower intensity.

Therefore, two surfaces perceived by a human as equally bright, with one being red and the other green, would be perceived by a dog as having almost the same hue but differing in brightness (the red one perceived darker than the green). The exact brightness difference perceived by a dog is hard to estimate as it depends on the spectrum of the reflected light and the neural processing in the dog's visual cortex. Based on the overlap of the sensitivity curve of the human red and green photo pigments we estimated that a red surface would be perceived by a dog as having only 40% of the brightness of a green surface. According to this, the color values for the simulated image are calculated from the original values as follows: $SimBlue = OrigBlue$; $SimGreen = [OrigGreen + (OrigRed \times 0.4)] / 1.4$. To achieve that what the dogs see as a neutral hue will also be neutral on the simulated image for the human eye, the red color value in the simulated image is made equal to the green color value ($SimRed = SimGreen$). A demonstration of the deuteranopia effect can be observed in Figure A1.

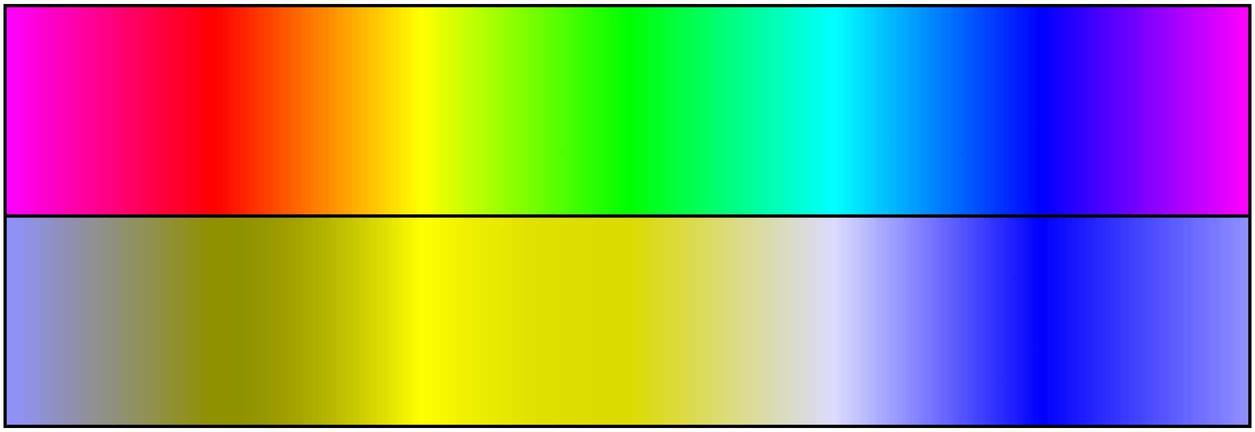

Figure A1. A complete RGB color spectrum (above), and the same spectrum processed by the algorithm that produces the deuteranopia effect (below).

During this process the overall brightness of the image can change. An additional algorithm (not described here) compensates for this effect, so that the processed image will have the same overall brightness as the original. Additionally, luminance values are always encoded in a nonlinear way in digital images (gamma compression). This means that before any operation that would require linearity of the data, the luminance values have to be gamma expanded and after the manipulation gamma compressed. We applied these steps each time, before and after manipulating the image data.

7.2 Visualizing the differences in brightness discrimination

To visualize the two times weaker brightness discrimination of dogs, the brightness range of the image has to be decreased by a factor of two. This can be done by dividing the RGB color values by two, but this also leads to a darkening of the image. To compensate for this effect the average brightness of the original image has to be calculated first. When calculating the average brightness, the three color channels are taken into account with different weights, to account for the differing sensitivity of the human eye for each hue [29]: *AvgBrightness* = (*AvgOrigRed* × 0.30) + (*AvgOrigGreen* × 0.59) + (*AvgOrigBlue* × 0.11). After obtaining the average brightness, the brightness range of the image is compressed by applying the following formula to every RGB color value: *SimRGB* = (*OrigRGB* + *AvgBrightness*) / 2. A demonstration of the effect of the brightness range decreased by a factor of two can be observed on Figure A2.

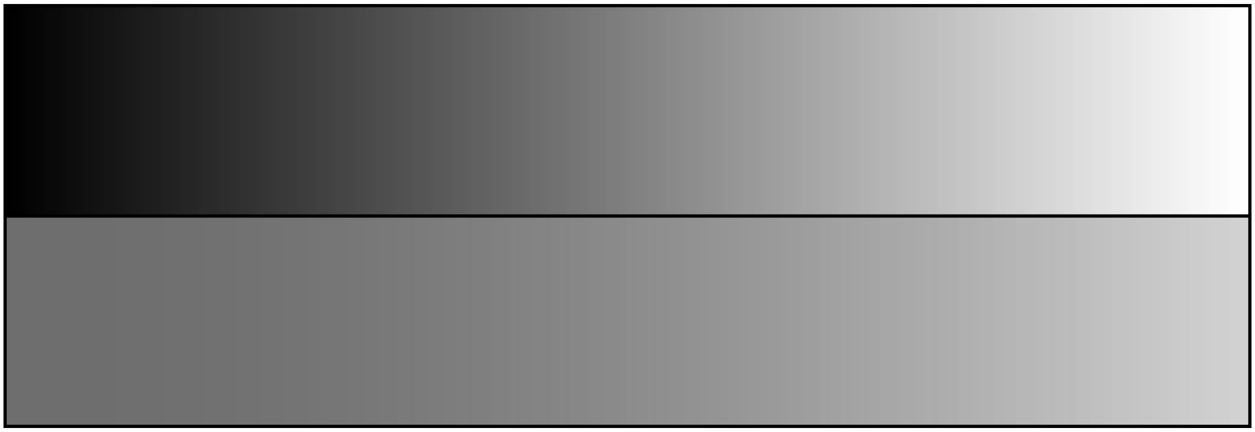

Figure A2. A continuous gradient from black to white (above), and the same gradient processed by the algorithm that halved the dynamic range (below).

7.3 Visualizing the differences in visual acuity

Showing the effects of decreased visual acuity can be achieved by blurring the image. One method to achieve this is to average the values of neighboring pixels. For performance reasons a linear blur algorithm was used. This algorithm processes the image in two passes: a horizontal and a vertical pass. In the horizontal pass it calculates the average of the value of the actual pixel and a certain number of pixels to the left and to the right, and then it replaces the actual pixel's value with this average. The vertical pass is the same with the difference that instead of using the left and right neighbors of the actual pixel, the pixels above and below are used to calculate the average. The averaging is done separately for all color channels.

The number of neighboring pixels included in the calculation (averaging window) influences the amount by which the image will be blurred. For decreasing the image details by a factor of 2, half of the left neighbor, the actual pixel and half of the right neighbor is used for calculating the average (averaging window = 2 pixels). For decreasing the image details by a factor of 3, half of the second left neighbor, the left neighbor, the actual pixel, the right neighbor and the half of the second right neighbor is used (averaging window = 4 pixels). For decreasing the image details one step further, one more of the left neighbors and one more of the right neighbors have to be used for calculating the average (averaging window = (decrease factor – 1) × 2).

However, there is a problem with this approach. Blurring with only one averaging window can leave details visible that are smaller than the averaging window. To overcome this problem the blurring has to be applied incrementally. For example when aiming to reduce the image details by a factor of 4, first a blur with an averaging window of 2 pixels, then a second one with an averaging window of 4 pixels and finally a third one with an averaging window of 6 pixels has to be performed. A demonstration of the effect of different amounts of reduction of image detail can be observed on Figure A3.

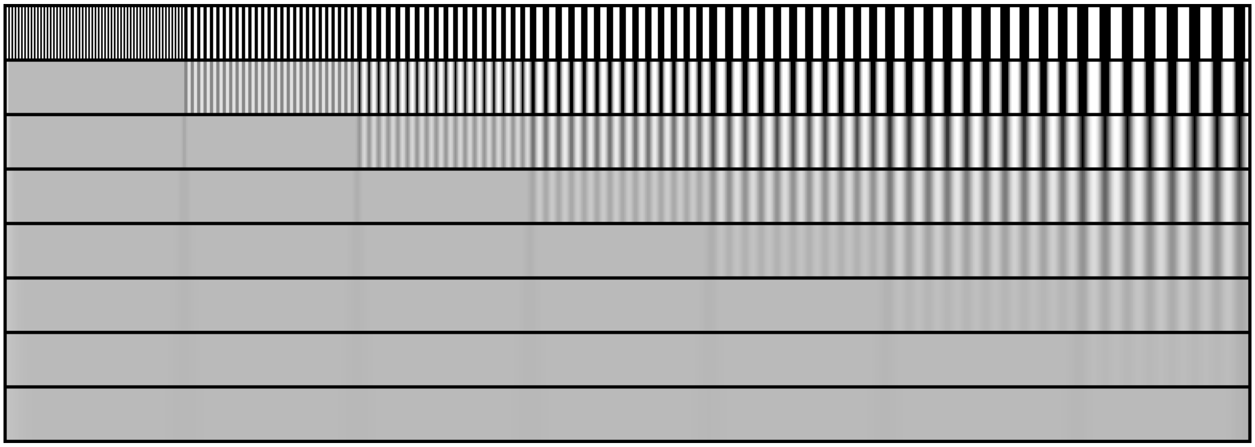

Figure A3. Black and white gratings with a bar width of 1 to 7 pixels. The topmost image is the original, below from top to bottom is the same grating showing the effects of decreased visual acuity by a factor of two to eight.