INVESTIGATING THE ROLE OF SPATIAL FREQUENCY BANDS IN DRAWING

by

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Abstract

To investigate the role of various bands of spatial frequencies for drawing, untrained artists drew four portraits from four different bands of spatial frequencies (e.g. unfiltered, 4-8, 8-16, & 16-32 cycles per face width (c/fw)). Raters then judged the accuracy of the drawings in comparison to both the source image from which the drawings were produced and an unfiltered version of the same face. The results show that low spatial frequencies (LSFs) and high spatial frequencies (HSFs) were useful for drawing, relative to middle spatial frequencies (MSFs). Additionally, the unfiltered condition that contained all spatial frequencies produced the most accurate drawings. This suggests that when artists are allowed access to both LSFs and HSFs they are able to utilize the global structure information carried in LSFs as well as the edge and detail information carried in HSFs to create more accurate drawings. The author posits that the MSFs that are useful for face recognition become redundant for drawing and that novice artists discount these MSFs in the control condition in order to increase the saliency and usefulness of the LSFs and HSFs. The results have implications for art education, drawing technology and the development of low-level drawing theory.

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Dedication

I would like to dedicate this work to my parents, Mark and Debra Freeman, for their constant support throughout my education.

CHAPTER 1 - Investigating the Role of Spatial Frequency Bands in Drawing

In past research, drawing has been utilized by researchers from various disciplines as a tool for evaluating perception (Marshall & Halligan, 2004; Rubens & Benson, 1971; Shulman, 2000; Van Sommers, 1984). For example, it has been used to demonstrate and probe the profound perceptual effects of damage to the right parietal lobe that manifest as "left" or "spatial" neglect (Marshall & Halligan, 2004). Another example of drawing's utility for perceptual assessment can be found in the literature on visual agnosia. Riddoch and Humphreys (1987), presented the case of H.J.A., a patient afflicted with visual agnosia. H.J.A. could not draw objects from observation however, when asked to draw objects from memory he encountered no problems. The use of drawing in this clinical study provided new insight into visual agnosia and serves as an excellent example of researchers using drawing as an evaluative tool. Beyond its utility in a clinical setting, drawing is a method of output that lends itself to experimental manipulation and investigation. This makes drawing a suitable methodological tool for researchers interested in probing the psychological processes involved in the creation and evaluation of art. As early as 1849 artists have recognized the existence and importance such psychological processes. Delacroix, a 19th century French painter, wrote,

> "…art is no longer what the vulgar think it to be, that is, some sort of inspiration which comes from nowhere, which proceeds by chance, and presents no more than the picturesque externals of things. It is reason itself, adorned by genius, but *following a necessary course* and *encompassed by higher laws* [emphasis added](1972, pp. 194-195)."

The relevant research suggests that drawing is poised to become a powerful cognitive assessment tool but, before it can do so, we must first gain an understanding of the numerous perceptual processes that accurately drawing entails. Furthermore, the reviewed literature makes clear that the cognitive processes involved in drawing are worthy of empirical investigation.

A Cognitive Approach to Drawing

Earlier drawing research has empirically investigated the cognitive processes involved in the creation and evaluation of art and has done so with mixed results (Cohen & Bennett, 1997; Cohen, 2005; Fish & Scrivner, 1990; Frith & Law, 1995; Gowen & Miall, 2006; Kozbelt, 2001; Miall & Tchalenko, 2001; Mitchell, Ropar, Ackroyd & Rajendran, 2005; Solso, 2001; Tchalenko, 1991; Tchalenko, 2007). Cohen and Bennett (1997) investigated multiple factors that they hypothesized to be possible determinants of one's ability (or inability) to accurately render an image. These factors included the influence of motor skills, decisions of what details to render, perception of one's own drawing, and perception of the to-be-drawn stimulus. Upon investigation of these variables, Cohen and Bennett deduced that the only factor that significantly contributed to drawing accuracy was one's perception of the to-be-drawn stimulus. In addition, a number of studies have investigated the role of eye movements in the drawing process (Cohen, 2005; Miall & Tchalenko, 2001; Tchalenko, 2007; Miall & Tchalenko, 2008), and they suggest that the less time that visual information is held in visual working memory, the less susceptible it is to perceptual distortions stemming from top-down processes, thus lending further support for the importance of perceptual processes in drawing. Perception of the stimulus is therefore an important issue in drawing, which is investigated in the following study. I begin to address this under-developed idea by looking at the drawing process through the lens of well-founded principles of spatial vision that deal with low level perception. Because portraiture is a common drawing practice, I ask the question, does the low-level perceptual information of a face, and the human visual system's sensitivity to that information, affect people's ability to draw faces accurately?

Spatial Vision in Perception

In the study of visual perception, spatial frequencies are often used as a means of measuring the limits of the visual system. The term "spatial frequency" is a measurement that describes the number of cycles of a sine wave in a given unit of space. Research concerned with the relationships between the spatial frequencies contained in a visual stimulus and human visual sensitivity to those frequencies is generally referred to as the study of spatial vision. Common stimuli used by spatial vision researchers are sine wave gratings. An example of a sine wave grating can be seen in Figure 1. In spatial vision, the unit of measurement used to describe spatial frequencies is usually cycles per degree of visual angle (i.e., c/d or cpd), where "cycle" refers to one cycle of a sine wave (from 0-2π on the unit circle). However, the denominator of this measurement may be tailored to suit researchers' needs depending on what level of analysis they are interested in. For the purposes of the reviewed face recognition literature, as well as the proposed studies, spatial frequencies will be described in cycles per face width (i.e., c/fw) and refers to the number of cycles a given sine wave may complete within the unit of space defined by the boundaries of the face stimuli.

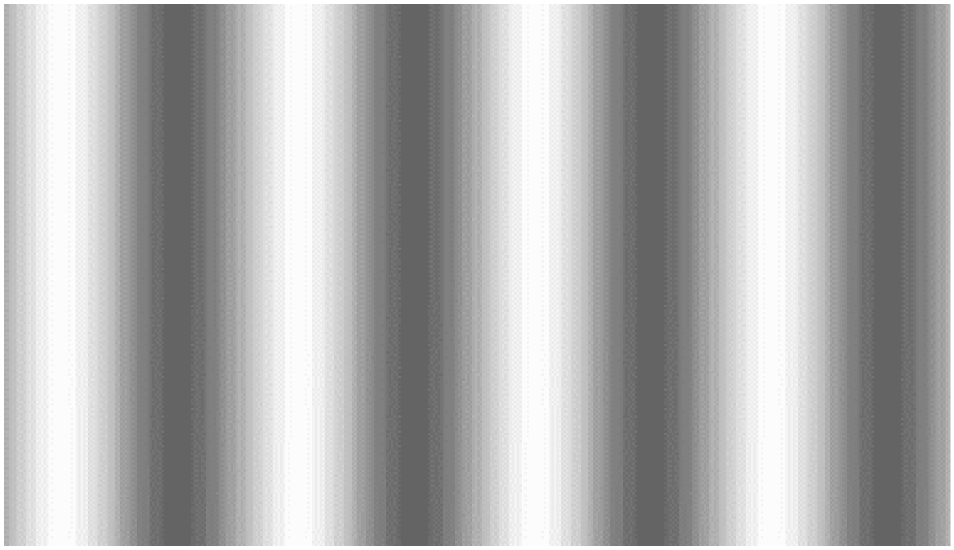

Figure 1. A sine wave grating of about four cycles in the width of the image (cycles/ image width).

Spatial frequencies do not have to be described individually and may be organized into groups of frequencies termed “bands.” Different spatial frequency bands convey specific information about the appearance of a stimulus. For example, higher spatial frequencies typically convey edge information and fine detail of the stimulus whereas lower spatial frequencies carry information regarding the global structure and orientation of the stimulus. Because normal images contain a full range of spatial frequencies, in order to isolate specific frequencies researchers must apply spatial filters to the images. Spatial filters can be implemented using sophisticated computer algorithms that isolate frequencies of interest and “filter out” the rest. In addition to computer implemented spatial filters, research has also shown that the mammalian visual system operates in a similar manner, with cells in area V1 tuned to be sensitive to specific bands of spatial frequencies (De Valois & De Valois, 1980).

In discussing the limits of the visual system, a common topic is visual acuity. Visual acuity is often measured by determining the number of cycles that the visual system can resolve in a given area. Higher visual acuity is indicated by the ability to resolve a greater number of cycles of a sine wave grating in a given area. However, visual acuity is directly affected by the amount of contrast present in a sine wave. The contrast of a sine wave is expressed by its amplitude (where amplitude and contrast are interchangeable terms). Figure 2 presents this issue graphically by plotting spatial frequency on the abscissa and contrast on the ordinate. In Figure 2, you can see the inverted-U-shaped line at which the various frequencies become imperceptible (no different from even gray). This line is the Contrast Sensitivity Function (CSF) and nicely illustrates the limits of our visual system. At the very low and very high ends of the spatial frequency scale, greater contrast is needed to resolve the alterations of light and dark. Less contrast is needed to resolve the middle spatial frequencies showing that we are more sensitive (i.e., better able to resolve) these frequencies. This concept of differential sensitivity to spatial frequencies is important for the present study because plots of the available information in the present filtered face stimuli would be located at different locations in this graph space, indicating real perceptual differences in the stimuli. This is an important concept for the present study because these differences in sensitivity could be an underlying mediator of any observed differences in drawing accuracy from condition to condition. However, a full analysis of the effect of contrast sensitivity is outside the scope of this report.

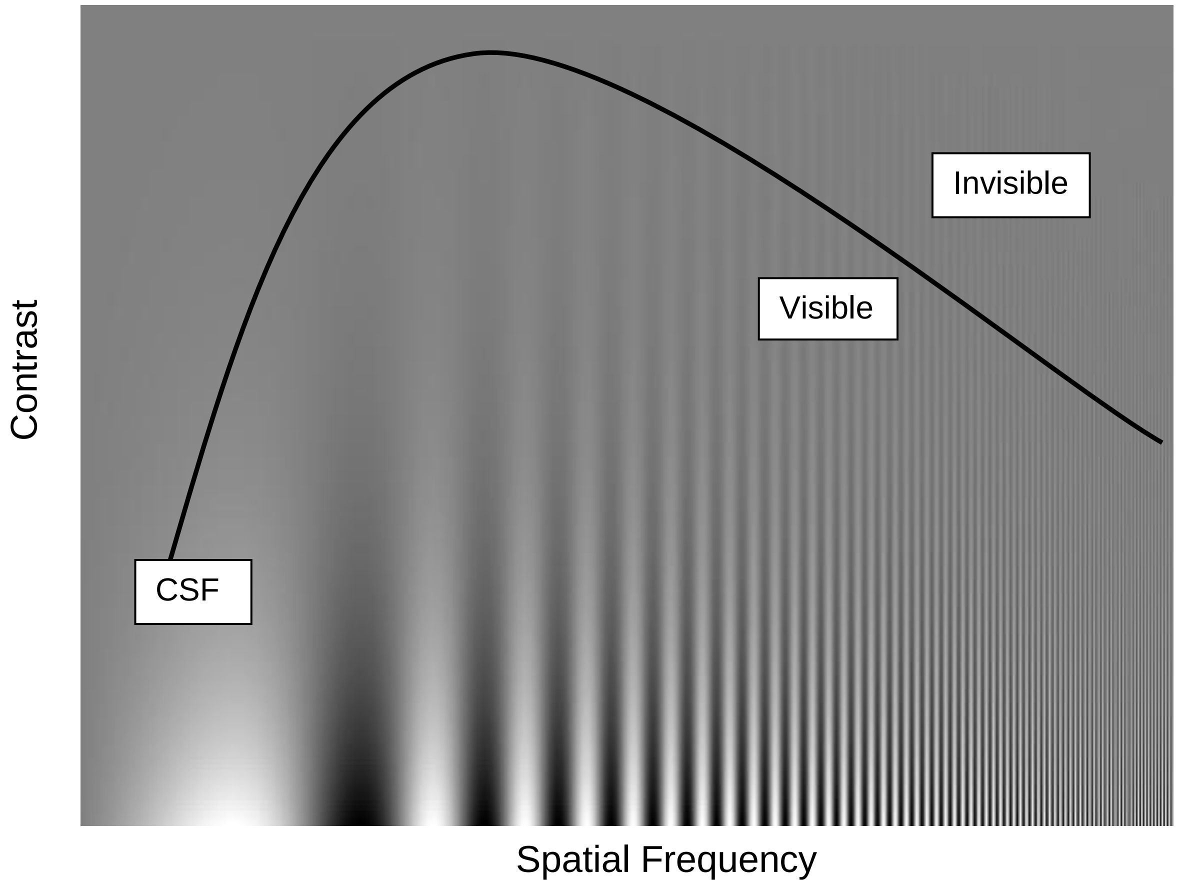

Figure 2. The contrast sensitivity function for a range of spatial frequencies at different levels of contrast.

A common method used for determining the amount of information conveyed in a given band of spatial frequencies is to measure the size of the spatial frequency band using octaves. An octave is essentially a doubling of frequencies so that, given a constant area, less low, and more high, spatial frequencies will fit into the area. To give a concrete example, a band of frequencies that is one octave wide could range from 4-8 cycles per unit space. A one octave step up from this band would a grouping of spatial frequencies ranging from 8-16 cycles per unit space, and then 16-32 cycles per unit space.

This method of octave stepping to determine bands of spatial frequencies is common in the face recognition literature and is the method used for determining the conditions in the current study using face width as the unit of space. Furthermore, this method for determining the stimuli used in the present study is useful because the spatial frequency sensitivity of cells in the primary visual cortex is also tuned to filter visual information in roughly 1-2 octave-wide frequency bands (De Valois & De Valois, 1980).

Because the participants in the current study are asked to render portraits, it is useful to ask what these principles of spatial vision can tell us about the perceptual processes involved in face recognition.

The Role of Spatial Frequencies in Face Recognition

Research generally agrees that our visual system utilizes spatial filters and differentially processes visual information carried in specific bands of spatial frequencies (Campbell & Robson, 1968; DeValois & DeValois, 1980; Schyns & Oliva, 1994; Vasilev & Stomoyakov, 1987). How people use various bands of spatial frequency information has been shown to be affected by task demands. For example, when subjects were asked to identify whether or not a face was expressive, they tended to utilize low spatial frequencies (LSFs) but, when they were asked to categorize the expression (happy or angry) they relied on high spatial frequencies (HSFs) (Schyns & Oliva, 1999). Similarly, research has shown that the configural (i.e., face as a whole) and featural (i.e., feature by feature) processing of faces is differentially influenced by low and high spatial frequencies respectively (Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Keil, 2009).

A common topic in the face recognition literature concerns humans' use of spatial frequency information when attempting to recognize and/or identify faces. Subjects are typically presented briefly with face stimuli that have been band-pass filtered at various spatial frequency cut-offs to only allow the viewer access to limited information (e.g., global or local information). These studies have consistently shown that a specific one-octave-wide spatial frequency band (8-16 c/fw) is optimal for face recognition tasks (Braje, Tjan, & Legge, 1995; Collin, Thierrien, & Martin, 2006; Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983; Gold, Bennett, & Sekular, 1999; Nasanen, 1998; Parker & Costen, 1999; Sinha, 2002). These findings have been used to determine the spatial frequency characteristics of the stimuli used in the current study, namely band-limited faces. This is text for the new sub section. It's rare to use a 4th level subheading, but Heading 5 style is available if you need it.

A Pilot Study

This method was also used for developing the stimuli in a pilot study by Freeman and Loschky (unpublished). Of chief interest to Freeman and Loschky was the question of which spatial frequencies would, when used first, facilitate the most accurate drawing by non-artists. Freeman and Loschky were interested in how artists use spatial frequencies early in the drawing process. Which order of frequencies could be used to render an image most accurately? Do artists have a preferred order in which they select out and utilize spatial frequencies present in an image? Do artists preferentially select out a specific range of spatial frequencies?

To investigate these questions, three male portrait photographs were band-pass filtered into three one-octave-wide bands of spatial frequencies. The spatial frequency bands were 4-8, 8-16, and 16-32 cycles per face width (c/fw) with equalized mean luminance. Each filter level was presented first in two conditions and was followed by the remaining filter levels. The three levels were presented in all six possible orders.

The face stimuli used in Freeman and Loschky's pilot study are presented in Figure 3 (excluding Face 4 and the Control column). Face stimuli were chosen and constructed for four reasons. First, in drawing, portraiture is a common practice. Second, a wealth of literature exists that documents how people use spatial frequencies in face recognition tasks (Boutet, Collin, Faubert, 2003; Braje, Tjan, & Legge, 1995; Collin, Thierrien, & Martin, 2006; Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983; Gold, Bennett, & Sekular, 1999; Nasanen, 1998; Parker & Costen, 1999; Sinha, 2002). Third, Freeman and Loschky kept with convention, as other drawing research has used face stimuli (Cohen & Bennett, 1994; Cohen, 2005; Miall & Tchalenko, 2001; Solso, 2001). Lastly, when drawings have been used as a perceptual assessment tool, a face is a common test item (Marshall & Halligan, 2004; Rubens & Benson, 1971).

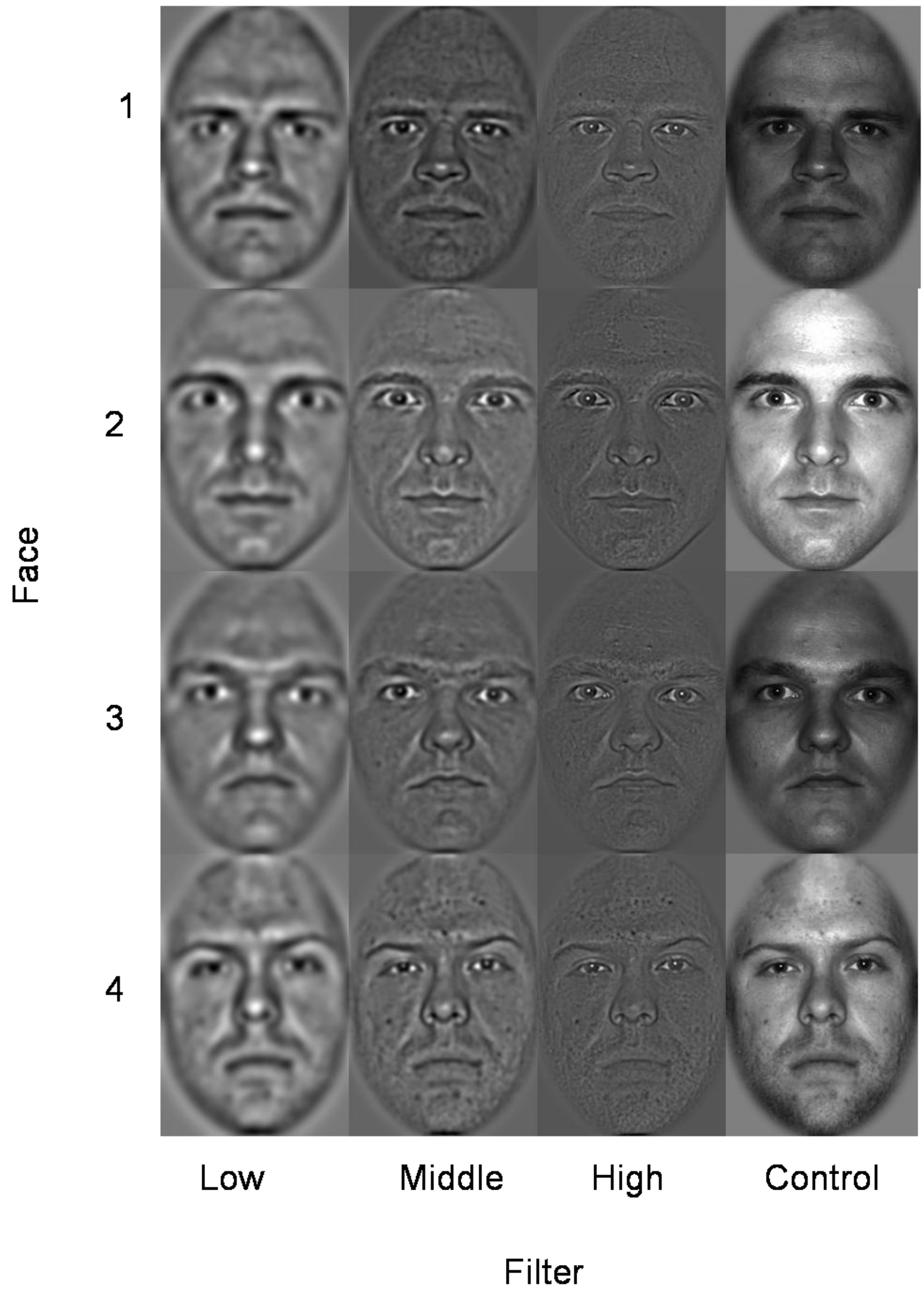

Figure 3. The stimuli used in the current study. Faces 1 – 3 (control column omitted) were used in Freeman and Loschky's pilot study. The Low column contains faces filtered to contain a one-octave wide band of spatial frequencies ranging from 4-8 c/fw. The Middle column contains faces filtered to contain a one-octave-wide band of SFs ranging from 8-16 c/fw. The High column contains faces filtered to contain a one-octave wide band of SFs ranging from 16-32 c/fw. The Control column contains unfiltered faces.

The results from Freeman and Loschky (pilot data) are presented graphically in Figure 4. While the results of Freeman and Loschky were not statistically significant, an obvious trend with a moderate sized effect of spatial frequency order was observed, *partial* $\eta^2 = .162$. The non-significant trend shows that conditions in which subjects produced drawings first using the HSFs produced the most accurate drawings. One explanation of this trend is that the common drawing practices used by artists and non-artists are likely a result of their reliance on HSFs to extract edge and spatial configuration information. Furthermore, according to Biederman and Ju (1988), edges and vertices (carried in HSFs) are critical for the recognition of objects. In their experiment they conveyed "edges" using simple line drawings of objects' essential contours. According to Biederman's Recognition-by-Components theory (Biederman, 1987), edge information allows one to extract individual geons[1] and thus accurately render individual structures (here facial features). Together, these ideas are consistent with the claim of Cohen and Bennett (1997) that the processes involved in perception of the to-be-drawn stimulus are a critical determinant of one's ability to accurately render a stimulus.

Consider for a moment the task of drawing a face presented in a limited band of spatial frequencies. Considering the evidence from the reviewed face recognition literature, it seems plausible that there may be an optimal band of spatial frequencies that will be of greater utility to artists and facilitate more accurate drawing than an alternate band of spatial frequencies. Results from Freeman and Loschky's pilot study support this speculation, though the data suggests that the most useful band may not be between 8-16 c/fw (as suggested by studies of the frequency band most useful for face recognition), but instead may be from 16-32 c/fw (their HSF condition).

[1] Geons is short for "geometrical ions" and is the term that Biederman (1987) uses to describe the individual 3D geometrical forms that come together to compose objects.

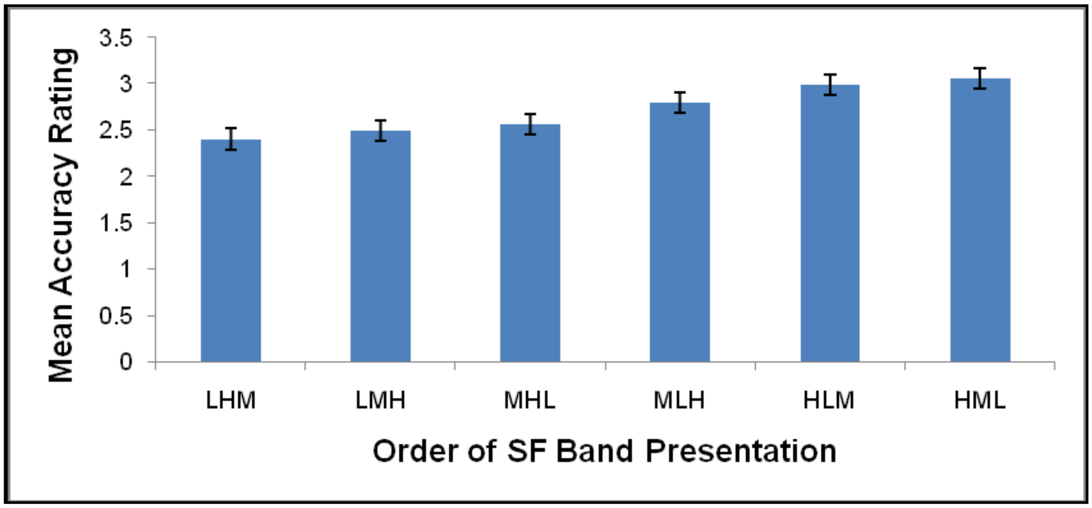

Figure 4. The results from Freeman and Loschky (pilot data). Mean accuracy of drawing ratings by the temporal order of spatial frequency band presentation. The error bars represent SEM. L = Low spatial frequencies, M = Middle spatial frequencies, & H = High spatial frequencies.

Freeman and Loschky noted the low power of the data analysis and, despite efforts to increase it, the power remained low. The effect appears to have been present but the design may not have allowed for the detection of a *statistically significant* effect. This line of thinking suggests two problems in the design of the Freeman and Loschky pilot study that may have led to the lack of statistically significant effects.

First, the design was overly complex with multiple levels of multiple variables. Three different levels of the "Face" variable and six spatial frequency orders resulted in a 3 x 6 mixed factorial ANOVA with "Face" treated as a repeated measure. The study was designed to allow the authors to account for the variance resulting from the variable of interest (e.g., spatial frequency order) as well as the nuisance variable (e.g., face). However, because of the complexity of this design, the authors were not able to gather a sufficiently large sample size to obtain stable data. Thus, this design did not provide the authors with the analytical power they needed to pull out a seemingly meaningful effect.

Second, each artist rendered drawings in a single spatial frequency order (i.e., spatial frequency order was a between-subjects factor). Participants randomly varied in their drawing skill, which was a nuisance variable in the study that was unaccounted for. Thus, the between-subjects error variance in drawing accuracy may have made it difficult to detect a significant main effect of spatial frequency order. The current study attempts to circumvent the above design issues by using a within-subjects design with fewer factors and conditions.

The pilot study of Freeman and Loschky was a reasonable start at investigating these issues, but failed to provide conclusive evidence on the question of the relative utility of different spatial frequency bands in the drawing process. Specifically, due to the complex design and the confounding of random between-subject variability in artistic ability with spatial frequency filter order through the use of a between-subjects design, the effects observed failed to reach significance. Furthermore, it was unclear whether a) the artists were exploiting spatial frequency information in a preferred temporal order or b) using the HSFs first simply allowed them to map out edges and thereby produce more accurate drawings. These uncertainties were addressed in the current study in an attempt to disentangle previous results and further understand the role of specific bands of spatial frequencies in the drawing process.

The Case for the Utility of HSFs, MSFs and, LSFs for Drawing

High Spatial Frequencies

Above, the terms, "HSF" and "edge information" have been used in such a way that suggests the terms are interchangeable. Typically, edge information is conveyed in HSFs; however, edge detection algorithms must use LSFs in order to locate and define edges (Canny, 1986). Thus, any edge image is the result of mainly high but also low and middle spatial frequencies (MSFs). This makes the distinction between HSFs and edges uncertain and justifies the inclusion of isolated LSF and MSF conditions in the current study so that the independent contributions of LSFs and MSFs to the drawing process could be assessed. Furthermore, if HSFs are particularly useful for drawing faces, then this can be shown by comparison with a LSF condition that contains none, and which should therefore produce much worse performance.

Observations of common, everyday drawing processes, of artists and non-artists alike, suggest that people outline objects' boundaries and edges (conveyed in HSFs) and then fill in with shadows, shading and large regions of color (conveyed in MSFs and LSFs) (Edwards, 1999). The familiarity of this common drawing practice could suggest why we may observe advantages of first using HSFs and following with MSFs and LSFs when attempting to render an image accurately. Edges seem to be important during the creation of art. In fact, Delacroix wrote in one of his personal journals that when drawing an object, people should start by rendering its principal lines (i.e., edges) (Delacroix, 1972). In this case, it is likely that the reliance upon HSFs is responsible for the common drawing practices used by both artists and non-artists. These arguments for the role of HSFs in object recognition and in common drawing practice motivate further research aimed to answer questions regarding artists' use of HSFs. The inclusion of a HSF-only condition will allow us to evaluate the independent contribution of HSFs to people's ability to draw accurately.[2]

Middle Spatial Frequencies

Also recall that the face recognition literature generally agrees that there is an optimal mid-ranged band of spatial frequencies that is optimal for face recognition and/or face

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[2] An apparent paradox that arises out of the distinction between HSFs, LSFs, and edges is that artists tend to convey global forms through the use of outlines. Global forms are generally all that LSFs can convey, yet edges are conveyed by HSFs. This begs the question of which spatial frequency information is being used when artists follow this practice. However, as shown by Goffaux, et al. (2005), global forms can also be conveyed by HSFs which suggests that artists may utilize HSFs in order to render global forms as well as edges and fine detail.

identification (Boutet, et al., 2003; Braje, et al., 1995; Collin, et al., 2006; Costen, et al., 1996; Fiorentini, et al., 1983; Gold, et al., 1999; Nasanen, 1998; Parker & Costen, 1999; Sinha, 2002). Thus, it is plausible that mid-ranged spatial frequencies that are good for face recognition are also optimal for the drawing of faces. This possibility was tested in the present study with the inclusion of a MSF condition in which the subjects were asked to draw from an image that only provided a one-octave wide band of spatial frequencies from 8-16 cycles/face width consistent with the optimal band defined in the face recognition literature.

Low Spatial Frequencies

To make a case for the role of LSFs in drawing, one must consider the limited information that is carried in LSFs. When looking at the LSF faces in Figure 3, it is apparent that all detail and edge information is absent whereas the information that conveys the global structure of the image remains. When considering portraiture, two components constitute what makes a portrait "accurate." First, the individual features of a face (e.g. eyes, nose and mouth) must be rendered accurately with little omission of real detail and little addition of unreal detail. Rendering such aspects would seem to be made possible though HSFs which carry edge and detail information. The second component of an accurate portrait is proper spatial configuration of the individual facial features. In the case that individual facial features are drawn well, if their placement within the space defined by the area of face is incorrect, the portrait as a whole could not be considered accurate. Because LSFs carry such global information, their role in the drawing process may be to represent spatial configuration information.

In art instruction, a common method used to facilitate novice artists' accurate spatial configuration of objects in a drawing is to overlay a grid onto the to-be-drawn image. The use of such instructional methods suggests that the spatial arrangement of objects in a drawing is an important component of accuracy and that novice artists have difficulty learning how to master this aspect of drawing. Because no comparable instructional aid is used to support novice artists' rendering of edge information, it seems that at a novice level, edges carried by HSFs are easier to render than configural information carried by LSFs.

CHAPTER 2 - Assessing the Roles of Various Spatial Frequency Bands in Drawing: Questions and Hypotheses

Question 1

Biederman's influential Recognition-by-Components theory of object recognition (Biederman, 1987) is based largely on one's ability to perceive the vertices where individual objects come together to form the geons that make up an object. These vertices are conveyed primarily by HSFs. Schyns and Oliva (1994) address the issue of object recognition as it applies to the acquisition of scene gist. Schyns and Oliva state that while LSFs convey salient information about a scene's global structure, HSFs are used later in the scene gist recognition process for the precise recognition of diagnostic objects in the scene thus allowing for certain scene gist recognition. The evidence from Schyns and Oliva (1994) adds additional support to the criticality of HSFs for the clear representation of objects. Marr and Hildreth (1980) also argue that the accurate identification of objects is driven by the object's edges, which are carried in HSFs. So, as with object recognition, scene gist recognition and, as suggested by the unpublished pilot data of Freeman and Loschky, is it possible that HSFs carry some special importance in the perception of objects. Because the ultimate goal of drawing (at least for realism) is to convey a recognizable object, could it be possible that artists primarily make use of these HSFs for drawing? If this were the case, then would isolation and emphasis of this HSF information result in more accurate drawings? I test these questions by isolating a one-octave-wide band of HSFs and asking subjects to draw portraits from that information.

It is possible that when artists are provided with only HSFs they will produce the most accurate drawings (H1). If the HSF condition results in the most accurate drawings, it would be consistent with the findings from Freeman and Loschky (pilot data) where the conditions in which HSFs were presented first resulted in more accurate drawings. The common drawing practices of novice artists, in which essential edges are drawn to convey a subject, suggest that these edges have some extra importance that encourages their selection by humans for the drawing process. If so, the results would be consistent with findings from Biederman and Ju (1988), in which they showed that object recognition is possible using solely essential edge information, and would suggest that humans prefer to render those edges that are essential for object recognition. Edge and vertices information is carried in HSFs and is capable of facilitating object recognition. Thus, if we consider faces as objects, it is possible that HSFs provide the information most useful for artists to create recognizable drawings of faces.

Question 2

The face recognition literature generally agrees that a band of spatial frequencies ranging from 8-16 c/fw is optimal for face recognition and/or identification. Thus if the information that is useful for face recognition is the same information that is useful for face drawing then we might expect that the condition in which the middle band of spatial frequencies, specifically 8-16 cycles/ face width, would result in more accurate drawings. Thus, it is possible that just as MSFs are particularly useful for face recognition, they might also have utility for face drawing.

Considering this, it is possible that the best drawings will be produced in the MSF condition (H2). MSFs have consistently been shown to optimally facilitate face recognition.

Such a result would be consistent with the hypothesis that the very different tasks of face recognition and face drawing require the same band of spatial frequency information and could potentially work using a common mechanism. Further investigation to more fully understand this relationship would follow.

Question 3

Judging from assessment of the drawings from the Freeman and Loschky pilot study, as well as observations of common drawing practices, people tend to pick up on, and render, the edges of the to-be-drawn stimulus (here faces). This seems to point to the importance of edges that are presumably carried by HSFs. However, as shown by Canny (1986), it also requires LSFs for computer algorithms to locate edges. This suggests the possibility that LSFs may have some utility in the human edge detection process as well.

The results may show that the LSF condition allows our subjects to produce the most accurate drawings (H3). Given the degraded nature of the LSF images, this would be a surprising result. However, should this result be observed it would be consistent with at least two explanations. First, because only the configural information is available it would suggest the importance of that information. Perhaps the LSF information would facilitate accurate spatial representations by disallowing over-emphasis on the missing detail. Second, because LSF are processed first during facial expression detection (Schyns & Oliva, 1999), should the LSF condition benefit the subjects in the drawing task, it would suggest some common mechanism between these perceptual processes. However, we may also observe in this case that the spatial configuration of the features is accurate but the detail of the features themselves is poor. This would suggest the need for both LSF and HSF and we would expect higher accuracy in the control condition (H4). It is also useful to include the LSF condition as a further test of the above hypotheses that MSFs and HSFs are important for drawing. If so, then performance in the LSF condition should be very poor since it contains no MSFs or HSFs.

Additionally, Schyns and Oliva (1994) have noted that LSFs are selected *first* for the identification of scene gist. Other research (Goffaux et al., 2005) has shown that the global arrangement of facial features can be ascertained from LSFs. Because proper spatial configuration of constituent features is a large part of what constitutes an accurate drawing, it stands to reason that LSFs may be especially useful during portrait drawing. Thus an important question becomes, are LSFs especially useful during drawing relative to MSFs and HSFs? Conversely, if HSFs or MSFs are particularly important for drawing faces, this suggests that LSFs may not be particularly useful for this task.

Question 4

Questions have been raised regarding the utility of LSFs, MSFs, and HSFs, in the drawing process. Therefore, it is necessary to include a control condition in the proposed study as a test of how filtering images affects perception of them during drawing. The unfiltered control condition will contain the complete range of spatial frequencies. The question then becomes, is it better to have the full range of spatial frequencies rather than having access to only a small portion of them (e.g., LSFs, MSFs, HSFs)?

The control condition could produce more accurate drawings than the other conditions (H4). Should this occur, it would be consistent with the simple explanation that more information is better. Because the unfiltered control image contains the entire range of spatial frequencies I would conclude that all of the information is beneficial for drawing and that the filtering of images hinders peoples' ability to draw accurately.

Question 5

It is important to note that the accuracy ratings obtained in the present study were given by the raters at two different levels of analysis. All drawings that were completed in part one of the experiment were compared to an unfiltered version of the face from which they were drawn and rated on how accurately they represented the face. These same drawings were also compared to the source image from which they were drawn. In other words the drawings, as well as being compared against an unfiltered photo of the drawn face, were also compared to the original filtered version of the face that they drew from. Because the control condition image is the same in both the source and control comparison conditions, drawings completed from the unfiltered condition were only rated once to avoid repetition. This method of obtaining ratings allowed us to address a couple of questions that would have gone unanswered if faces were only compared to one of the images.

First, if the artists followed the instructions and only drew what they saw, then the drawings should look like the filtered images. Say for instance, I happened to have a naturally skilled artist participate in this study. If she were able to render the images exactly as they appeared, she would produce drawings that looked like band-pass filtered faces (e.g., LSF). If the raters were to rate the accuracy of her drawing of a LSF image as compared to an unfiltered image, they would likely rate the drawing as inaccurate even though the artist perfectly represented the information that she was given. Because it would be a mistake to penalize artists for accurately portraying the information given to them, it becomes necessary to obtain ratings of accuracy as compared to images that only contain the information to which the artist was granted access.

On the other hand, in order for us to draw conclusions regarding the utility of various band-limited spatial frequency information during drawing, it is necessary to gather ratings of how accurately the drawings represent objects as they exist in the world (i.e., in comparison to unfiltered images). Therefore, in addition to being compared to their source image, the drawings obtained in part one of this study were also compared to the unfiltered image of the face that they represent.

Assuming that the artists really drew what they saw and the raters understood their rating task, this dual comparison methodology leads us to one additional hypothesis regarding the relative comparison images. Accuracy ratings resulting from the various drawing conditions should be higher when raters compare them to their source images than when they are compared to the unfiltered images (H5). To test all of these hypotheses, the following methodology was used.

CHAPTER 3 - Method

Participants

The design of the current study presents an interesting question with respect to the two groups of participants; artists and raters. Specifically, only one of these two groups of participants can be treated as "subjects" in a within-subjects design. The primary independent variable in the study was the different spatial frequency bands presented to artists, which was expected to produce differences in the drawings produced by them. The primary dependent variable in the study was the ratings of those drawings, which would be produced by the raters. The question, therefore, was which group would be treated as the "subjects" in the within-subjects design. Since raters produce the dependent variable, one can consider their task as analogous to taking a test, with each drawing acting as an individual test item. From this perspective, the question is whether it is better to have more test takers (requiring more raters), or more test items (requiring more artists). Research suggests that increasing the number of test items (*k*) produces smaller benefits than increasing the number of test takers (*n*) (Holman, Glas, & de Haan, 2002). I therefore decided to have a larger number of raters than artists, and thus to treat raters as the "subjects" in our within-subjects design. This would increase the statistical power of the analyses, creating a greater probability of detecting meaningful differences, if they exist. In addition, having a smaller number of "test items" (produced by a relatively smaller number of artists) would help the raters maintain their focus of attention and thus produce cleaner data. As will be discussed below, the high inter-rater reliability produced by the raters confirms that this strategy worked as intended.

Artists

All subjects who drew the portrait stimuli are referred to as artists within the context of this experiment. Ten undergraduate students from Kansas State University were recruited as novice artists (7 female, Age: M = 20.3, SD = 5.2). They participated in the experiment for partial fulfillment of a research participation requirement form their General Psychology course. Consistent with past drawing research, our ten artists had no formal training in the visual arts (Cohen & Bennett, 1997). Given our subject pool (e.g., students in the general psychology courses at Kansas State University) and because it is difficult to rigidly control for drawing ability, our best shot at controlling for artistic ability was to simply ensure that none of the subjects had received formal training (and thus were relatively homogeneous in terms of their drawing skill). "Formal training" in the visual arts was operationally defined as having taken more than one art class at the college level and was assessed prior to the start of the experiment.

Thus, if any participant had exceeded more than one art class at the college level, they could not participate in this study.

Raters

All subjects who participated as critics of the accuracy of the drawings obtained in part one are referred to as raters within the context of this experiment. 63 undergraduate students from Kansas State University were recruited as novice raters (40 female, Age: M = 18.8, SD = 1.4). They participated in the experiment for partial fulfillment of a research participation requirement form their General Psychology course. Consistent with past drawing research, the novice raters had no formal training in the visual arts in accordance with the operational definition (Cohen & Bennett, 1997). Because art students are exposed to many different artistic styles (e.g., impressionism, expressionism, pop-art, etc.) and possess different preferences as to which aesthetic qualities they find interesting, it is plausible that instead of rating drawings simply on the basis of realism, trained artists would have rather used more sophisticated (i.e., aesthetic) criteria for judging the drawings. While the aesthetic quality of drawings is an interesting issue, it is outside the scope of this research. Thus it was important to use novice critics with no formal training in the visual arts, for whom it may have been more natural to rate the drawings solely on the quality of realism.

Stimuli

Artists

Four male faces were band-pass filtered at four levels (4-8c/fw, 8-16 c/fw, 16-32 c/fw and, unfiltered) and served as the LSF, MSF, HSF and, control images respectively. All face stimuli used in the current study are presented in Figure 3.

Raters

Digitized scans of the drawings produced by the artists will serve as the stimuli for the raters.

Experimental Setup

Artists

The experiment was run on Dell Optiplex 170L computers using Experiment Builder® software and presented on 17" ViewSonic CRT monitors. The artists were supplied with 8.5" x 11" white typing paper fixed to a clipboard to provide a stable and uniform drawing surface. The drawing tool was a sharpened #2 pencil with an eraser. The lay person's familiarity with a pencil, perhaps the most common drawing tool, makes pencil the ideal artistic medium for assessing perception in an experimental setting. No artists reported having problems using the pencil for drawing.

Raters

The rating experiment was run on the same Dell Optiplex 170L computers and 17" ViewSonic CRT monitors used in part 1. Experiment Builder® software was used to execute the experiment. Digitized scans of drawings obtained in part one of the experiment were presented on the monitor, adjacent to the source image (e.g., 4-8 c/fw, 8-16 c/ fw, 16-32 c/fw, line drawing, or control) from which the drawing was rendered or next to an unfiltered version of the same face (see Figure 5). This allowed us to obtain two separate measures of drawing accuracy. One measure given by the raters was based on a comparison of the drawing to the source image from which it was drawn and the other measure was given based on a comparison of the same drawing from the unfiltered version of that face. The order in which these comparisons were made was randomized. Taking ratings based on two comparison images (e.g., source and control) is important two reasons. First, because artists were instructed to draw only what they saw, it would put them at a disadvantage to have their drawings rated based solely on a comparison to an unfiltered image that contains information that they did not have access to when drawing from filtered images. Second, Because the appearances of the filtered and unfiltered images are very different, in order to obtain a clear picture of the cognitive processes of the artists and raters it is necessary to obtain ratings of how well the artists drew what they saw (source comparison) as well as how well they were able to use various bands of spatial frequencies to represent faces as they naturally appear (control comparison).

When each comparison was made (i.e., vs. source or vs. control) in the course of the experiment was randomized. The relative screen position at which the drawing or source image appears (either left or right) was also randomized and counter balanced. The raters used a mouse to manipulate a sliding scale that was located at the bottom of the computer display.

Procedure

Artists

The artists signed informed consent forms before being allowed to participate in the experiment. The artists then completed a vision test to ensure that they had normal or corrected-to-normal vision. A brief questionnaire ensured that the artists had no formal training in the visual arts. After completion of the preliminary paperwork and experiment introduction, the subjects were seated at 1 of 4 computers in the Visual Cognition Lab. The instructions were presented on the computer monitor. The instructions read as follows.

> *In this experiment you will be asked to draw a series of images. In total you will produce 4 drawings. Each image will be presented for 10 minutes. After you have reached the drawing time limit, you will be prompted to put your drawing aside and prepare to start a new drawing.*

ONLY DRAW WHAT YOU SEE. DO NOT draw what can be inferred from the image or what you may remember from previous images. For example, do not outline an eye if you cannot see the outline of an eye. Try to depict the present information as accurately as possible. You are allowed to erase and correct any mistakes. PLEASE DRAW FOR THE ENTIRE TIME THE IMAGE IS PRESENT.

We are not concerned with the artistic value of your drawing. Style, creativity and aesthetic value do not count. Only the accurate depiction of the images presented is important. Accuracy can be thought of as photographic realism. The more your drawing resembles the real life appearance of the image, the more accurate it will be. You will have 10 minutes to draw each image. When the time is up the image will disappear and you will be prompted to advance to the next image by pressing the SPACEBAR button. If you need to take a short break, please take it in between the presentation of the images. You will be drawing a total of 4 portraits. Do you have any questions? Please explain these instructions back to the experimenter.

If ready to proceed, press the SPACEBAR.

When finished reading the experiment instructions, the subjects began the experiment by pressing a key.

Every artist subject drew each face once from one condition (4 faces x 1 condition each = 4 drawings) with the pairing of face and filter condition completely randomized. The condition presentation order and which face was drawn are considered nuisance variables in this design and have been accounted for through the assumptions that accompany randomized designs.

Each face image condition had a total presentation time of 10 minutes, the total presentation time given in Freeman and Loschky (unpublished) and, Cohen and Bennett (1997). After completion of the experiment, the participants were debriefed and thanked for their participation. Their drawings were scanned into digital files and used as the stimuli in the raters' segment of the experiment.

Raters

All experimental protocols were the same as above except as follows. At the start of the experiment, information was presented on the computer monitor instructing the subjects how to complete the experiment. "Drawing accuracy" was operationally defined and the subjects were instructed how to make judgments of drawing accuracy. For the purposes of this experiment drawing accuracy was operationally defined as a "true-to-life representation of the source image." The instructions read as follows.

> *In this experiment you will be asked to rate the accuracy of a series of drawings. The drawings will be presented on this computer screen. You task is to compare the drawings to the source photograph that is presented next to the drawing and rate how accurately the drawing represents the photograph, using the sliding scale at the bottom of the screen. To operate the sliding scale, simply move the mouse. When the bar is where you think it should be, just click and this will set your rating. You may advance to the next drawing you are to rate by pressing the spacebar after you have set your rating. If you need to take a break, please do so in between ratings.*
>
> *The far left end of the slide represents less accurate drawings compared to the photograph while the far right end of the scale represents more accurate drawings. Do not use the extreme ends of the scale unless you are certain that the drawing could not be any worse or any better. I am not interested in the artistic value of the drawing. Style, creativity and aesthetic value do not count. Only the accurate depiction of the photographs in the drawings is important. Accuracy can be thought of as photo realism. The more the drawing resembles the real life appearance of the comparison image, the more accurate it will be considered. There is no time limit in this experiment so please take your time and consider all aspects of the drawing.*
>
> *You have been provided with an example of a well done drawing and an example of a poorly done drawing. The sliding scale underneath each of these examples is set to an appropriate rating. Even though these drawings are examples of extreme skill/ lack of skill, they are not rated at the extreme ends of the scale. Keep this in mind when making your judgments of the accuracy of the drawings. The complete ends of the scale should be reserved for very extreme cases. These pictures are to give you a reference point from which to make your ratings. You are allowed to go past the position of the bars in the picture if you truly believe that the image is either better than the good drawing or worse than the poorly done drawing. Please compare the drawings presented during this experiment, to the comparison photographs presented next to them, and make*

your rating according to how accurately the drawing represents the photograph. Please ask the experimenter any questions you have at this time.

Press the SPACEBAR to begin the experiment.

The raters were also provided with handouts picturing screenshots of example experiment screens that illustrated appropriate ratings for a poorly done drawing (lowest rated in the Freeman and Loschky pilot study) and an extremely well done drawing (highest rated in the Freeman and Loschky pilot study). This was intended to prevent a floor effect as none of our artists had formal training in drawing technique as well as to increase rating variability by encouraging use of the entire scale. The screenshot of a rating for a more accurate drawing is presented in Figure 5. This example drawing was chosen to give raters a realistic idea of the level of drawing accuracy that is possible to achieve in our procedure (based on the results of our previous study). To prevent end effects (i.e., ratings near the ends of the scale)(Marks & Gescheider, 2002), these extreme examples of drawing accuracy have been presented with assigned ratings 1/15th of the range of the scale in from the ends, corresponding to a rating of 7.3 for the low end and 92.7 for the high end.

The raters used the computer mouse to manipulate the sliding scale. The 100-point scale ranges in .10 increments from 0 to 10, where a 0 rating is the least accurate and a 10 rating is the most accurate. The anchors of the scale have been labeled accordingly (see Figure 5). After clicking the mouse to set their rating, the raters pressed the spacebar to advance to the next trial. The side of the screen on which the drawing and comparison source image are presented was fully randomized. The raters made a total of 70 ratings.

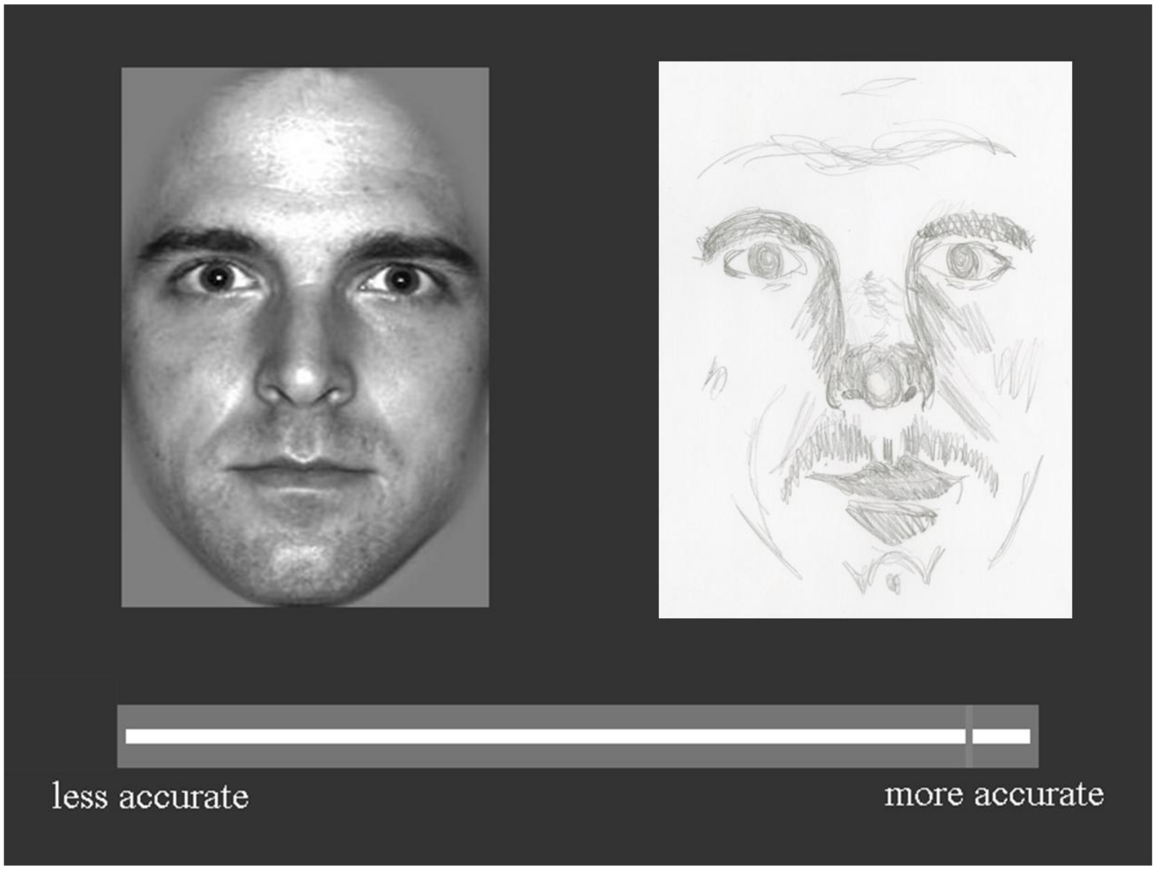


Figure 5. A screen shot of the experiment with the drawing presented adjacent to the source image containing all frequencies present to the artist. The sliding scale used to make the ratings is located beneath the two images.

CHAPTER 4 - Results

Prior to analysis, all accuracy ratings were normalized to each rater's range by creating within-subject *z*-scores for each rating. This was done to factor out between-rater variability in terms of the range of the scale that they use. Inter-rater reliability was then assessed for all of the ratings using Cronbach's α. The ratings exhibited high reliability, $\alpha = .97$.

Inspection of the data revealed a minor error in the experimental program. The data for artists 6 and 7 were unbalanced such that artist 6 had received no ratings for their drawing from the LSF condition while artist 7 received twice the amount ($n = 126$) of ratings for their control condition. Noting this, all analyses were run using the original dataset as well as a trimmed dataset with all data from artists 6 and 7 removed. Analyses were also run using only the data from artists 6 and 7.

Moving on, the rating data were filtered according to whether the drawings were compared to the source image from which they were drawn or the control image. Separate analyses were then run to test for any main effects the spatial frequency filters applied to the stimuli may have had on artist drawing accuracy.

Tests for Main Effect of Filter when Drawings were Compared to the Source Image

Including the ratings of drawings from artists 6 and 7, a one-way repeated measures ANOVA was used to test for the main effect of filter condition on rated accuracy. When the data were compared to the source image from which they were drawn the analysis revealed a significant main effect of filter, F (3,186) = 9.401, $p < .001$. Cohen's f (Kirk, 1995, pp. 180-182) was used to measure effect size and a moderately sized effect of filter was revealed, Cohen's f = .32. Multiple comparisons were completed using Bonferroni corrected t-tests. Effect sizes were calculated using Cohen's *d.*[3] The multiple comparisons showed that the drawings completed in the HSF filter condition were rated as significantly more accurate than the LSF (Cohen's d = .518, p = .037), MSF (Cohen's d = 1.113, $p < .001$) and control (Cohen's d = .616, p = .011) conditions. However, the drawings produced in the MSF condition were not rated as significantly different from those produced in the LSF condition (Cohen's d = .480, p = .116) or the Control condition (Cohen's d = .467, p = .099) although the MSF v. Control comparison is

[3] Effect sizes calculated using Cohen's d are interpreted as follows: Small = .20, Medium = .50 & Large = .80 (Cohen, 1992).

marginally significant. A comparison of ratings of drawings from the LSF condition to drawings from the control condition also failed to reach significance (Cohen's d = .488, p = 1).

Because the error in the experimental program produced an imbalance across experimental conditions for the drawings from artists 6 and 7, all trials containing their drawings were removed from the analysis. The analysis revealed that removing this imbalance in the design strengthened the effect of filter condition on rated accuracy, F (3,186) = 18.867, p < .001, Cohen's f = .46. The Bonferroni corrected t-tests showed a number of significant differences between the filter conditions. Drawings produced in the HSF condition were rated as significantly more accurate than those drawn in the LSF (Cohen's d = .666, p = .002) and MSF (Cohen's d = 1.162, p < .001) conditions. The drawings produced in the control condition were also rated as significantly more accurate than the LSF (Cohen's d = .781, p =.001) and MSF (Cohen's d = 1.288, p < .001) conditions. Two comparisons failed to reach significance; the comparison of the LSF condition to the MSF condition (Cohen's d = .442, p = .141) and HSF to control (Cohen's d = .113, p = 1). The means and standard deviations for the original and trimmed data are presented in Table 1and are presented graphically in Figure 6.

Because the drawings produced in the HSF condition are rated as more accurate, that suggests that the selection of HSFs is beneficial to drawing, more so than LSFs and MSFs. Further, because the HSF condition outperforms the LSF and MSF conditions, this is consistent with the hypothesis that the information conveyed in LSFs and MSFs is not as useful for drawing relative to HSFs. Additionally, when the data from artists 6 and 7 are removed, the mean rating of the control condition is slightly higher (M = .31, SD = .29) than that of the HSF condition (M = .28, SD =.29). Although this difference is not statistically significant, it is consistent with the simple hypothesis that more information is better. Furthermore, it also suggests that drawing from filtered images may be inherently difficult. Let us now examine the data pattern when drawings were compared to unfiltered images and rated for their accuracy of representation of that image.

Table 1

Mean Accuracy Rating of Drawings when Compared to Source Image

	All Artists			
	Low	Middle	High	Control
Mean Accuracy (*z*)	0.014	-0.11	0.15	0.001
SD (*z*)	0.285	0.229	0.238	0.246

	Trimmed			
	Low	Middle	High	Control
Mean Accuracy (*z*)	0.081	-0.0398	0.2767	0.3097
SD (*z*)	0.295	0.25	0.293	0.291

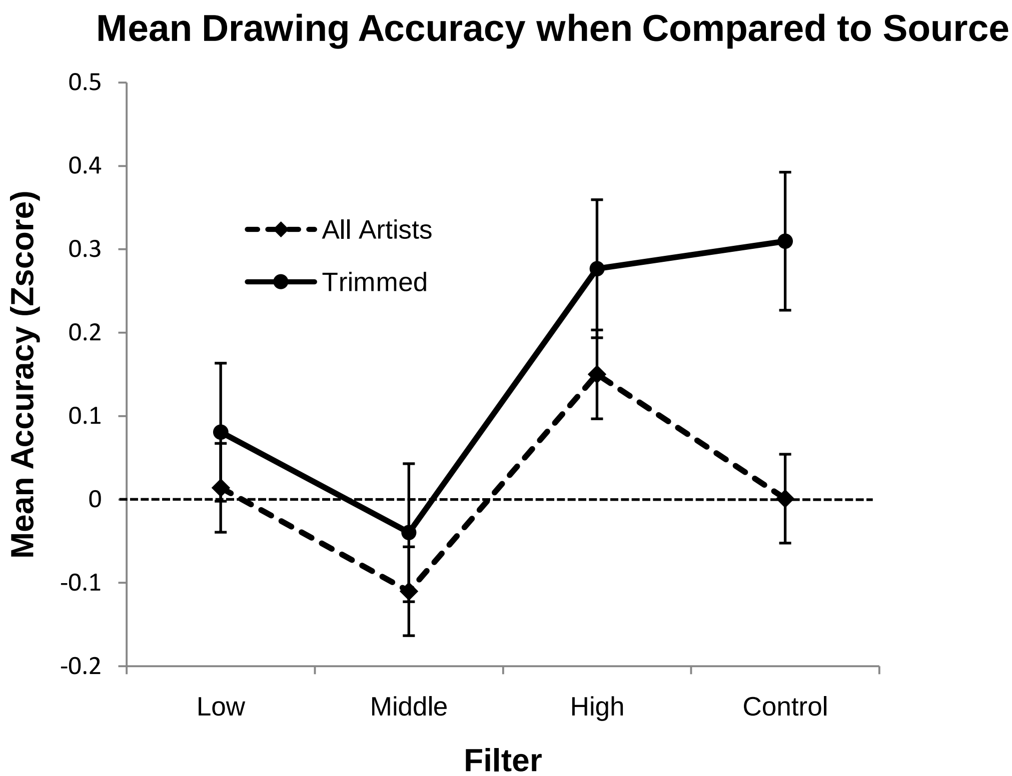


Figure 6. Mean drawing accuracy of the drawings when they were compared to their source image. The two lines represent the original and trimmed data. The error bars are based on SEM.

Tests for Main Effect of Filter when Drawings were Compared to the Control Image

Another one-way repeated measures ANOVA was run on the accuracy ratings given to the drawings from the four filter conditions when they were compared to the control image. Using the data from all artists, a significant main effect of filter was again revealed, F (3,186) = 3.621, p = .014, although the effect size was smaller than when compared to the source image, Cohen's f = .17. Multiple comparisons, again using Bonferroni corrected t-tests, showed that the drawings produced in the LSF filter condition were rated as significantly more accurate than those drawn from MSFs (Cohen's d = .52, p = .039) as were the drawings produced in the HSF condition (Cohen's d = .57, p =.05). These comparisons further revealed that the control condition failed to produce drawings that were rated significantly different from those in the LSF (Cohen's *d* = .075, *p* = 1), MSF (Cohen's *d* = .461, *p* = 1) or HSF (Cohen's *d* = .136, *p* = 1) conditions.

When the imbalanced ratings for artists 6 and 7 were removed, the effect was strengthened. The main effect of filter became much larger, *F* (3, 186) = 15.573, *p* < .001, Cohen's *f* = .42. The multiple comparisons revealed five significant differences between the filter conditions. The drawings rendered in the control condition received significantly higher ratings of accuracy than the LSF (Cohen's *d* = 1.35, *p* = .001), MSF (Cohen's *d* = 1.35, *p* < .001) and HSF (Cohen's *d* = .55, *p* = .019) conditions. Additionally, the LSF condition allowed for more accurate drawings than the MSF condition (Cohen's *d* = .54, *p* = .03). The MSF condition also produced less accurate drawings than the HSF condition (Cohen's *d* = .70, *p* = .005). The drawing produced in the LSF condition were not rated as significantly different from those produced in the HSF condition (Cohen's *d* = .203, *p* =1). The means and standard deviations for the original and trimmed data are presented in Table 2 and are presented graphically in Figure 7.

Table 2

Mean Accuracy Rating of Drawings when Compared to Control Image

	All			
	Low	Middle	High	Control
Mean Accuracy (*z*)	0.02	-0.116	0.036	0.001
SD (*z*)	0.262	0.261	0.269	0.246

	Trimmed			
	Low	Middle	High	Control
Mean Accuracy (*z*)	0.076	-0.076	0.138	0.31
SD (*z*)	0.279	0.28	0.331	0.291

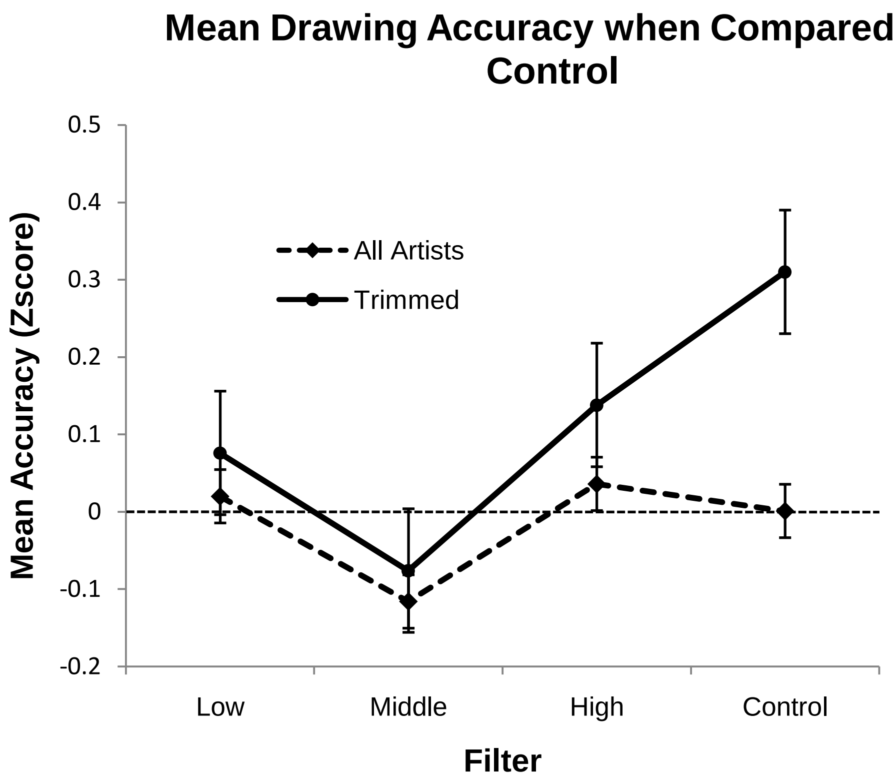


Figure 7. Mean drawing accuracy of the drawings when they were compared to the control images. The two lines represent the original and trimmed data. The error bars are based on SEM.

The Main Effect of Comparison

Because the data show that the image with which the drawing is compared changes the data pattern in an important way, analyses were then run to test for the main effect of comparison. What the data revealed is that when data from all artists are analyzed using a one-way repeated measures ANOVA, there is no main effect of comparison image, F (1, 62) = 3.144, p = .081. However, when the same analysis is conducted with data from artists 6 and 7 removed, the effect of comparison image is significant, F (1, 62) = 5.149, p = .027. Consistent with our fifth hypothesis, drawings tended to be rated higher when they were compared to their source image. However, Cohen's f tells us that this effect is relatively small, Cohen's f = .181. Figure 8 graphically presents the pattern of drawing accuracy for each filter condition when drawings were compared to their source image as well as when the drawings were compared to the control image.. When examining Figure 8 it seems that the effect of comparison is being driven by the difference of the ratings between the source and control comparison for the HSF condition. An independent samples *t*-test confirms this speculation. The accuracy ratings of drawings produced in the HSF condition differed significantly, t (1, 124) = 2.489, p = .014. This difference was dependent upon the whether the drawings were compared to the source (HSF filter) or control image. The HSF drawings were rated as more accurate when they were compared to the source image from which they were drawn.

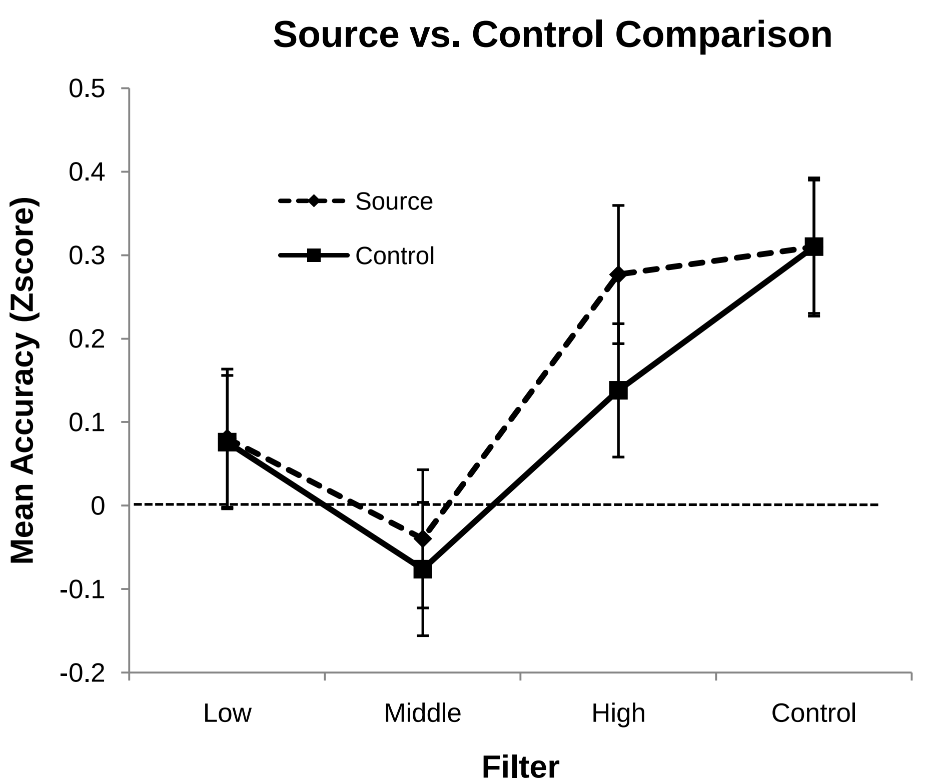


Figure 8. A comparison of the mean accuracy ratings in each filter condition for drawings compared to the source and control images.

Tests of Artists 6 and 7

Given that data from drawings by artists 6 and 7 were removed from the analyses, it is important to evaluate what exactly was being removed. Therefore, analyses were run to test for the main effect of filter when the drawings of artists 6 and 7 were rated against the source as well as the control images. When the drawings were compared to the source image, the data demonstrated a significant main effect of filter condition F (3, 186) = 11.129, p = .001. Multiple comparisons using Bonferroni corrected t-tests showed that the drawings produced in the control condition were rated significantly higher than those drawn in the LSF (p = .012), MSF (p < .001) and HSF (p < .001) conditions. These data are in line with the ratings of the drawings from the other eight artists.

Identical analyses were run on the accuracy ratings of artists 6 and 7 when their drawings were compared to control images. The data show a significant main effect of filter F (3, 186) = 12.749, p = .001. Again the drawings from the control condition were rated as significantly more accurate than those drawn from the LSF, MSF and HSF conditions (all *ps* = .001). An additional ANOVA tested for the main effect of comparison image. For the accuracy ratings of drawings from artists 6 and 7, there was no main effect of comparison image, F (1, 62) = 1.285, p = .261.

CHAPTER 5 - Discussion

The data from trials based on drawings by artists 6 and 7 were removed to correct for an imbalance in the rated conditions. Because any discussion of the data produced with this imbalance muddles the interpretation of the data, this discussion will focus only on the results from the analyses run with the data from artist 6 and 7 removed, as presented in Figure 8. A sample of the drawings produced in this experiment can be seen in Figure 9 organized by the filter condition they were produced from. Because each of these filters suggests something unique about the perceptual processes involved in drawing, I will consider each filter independently as well as the data pattern as a whole.

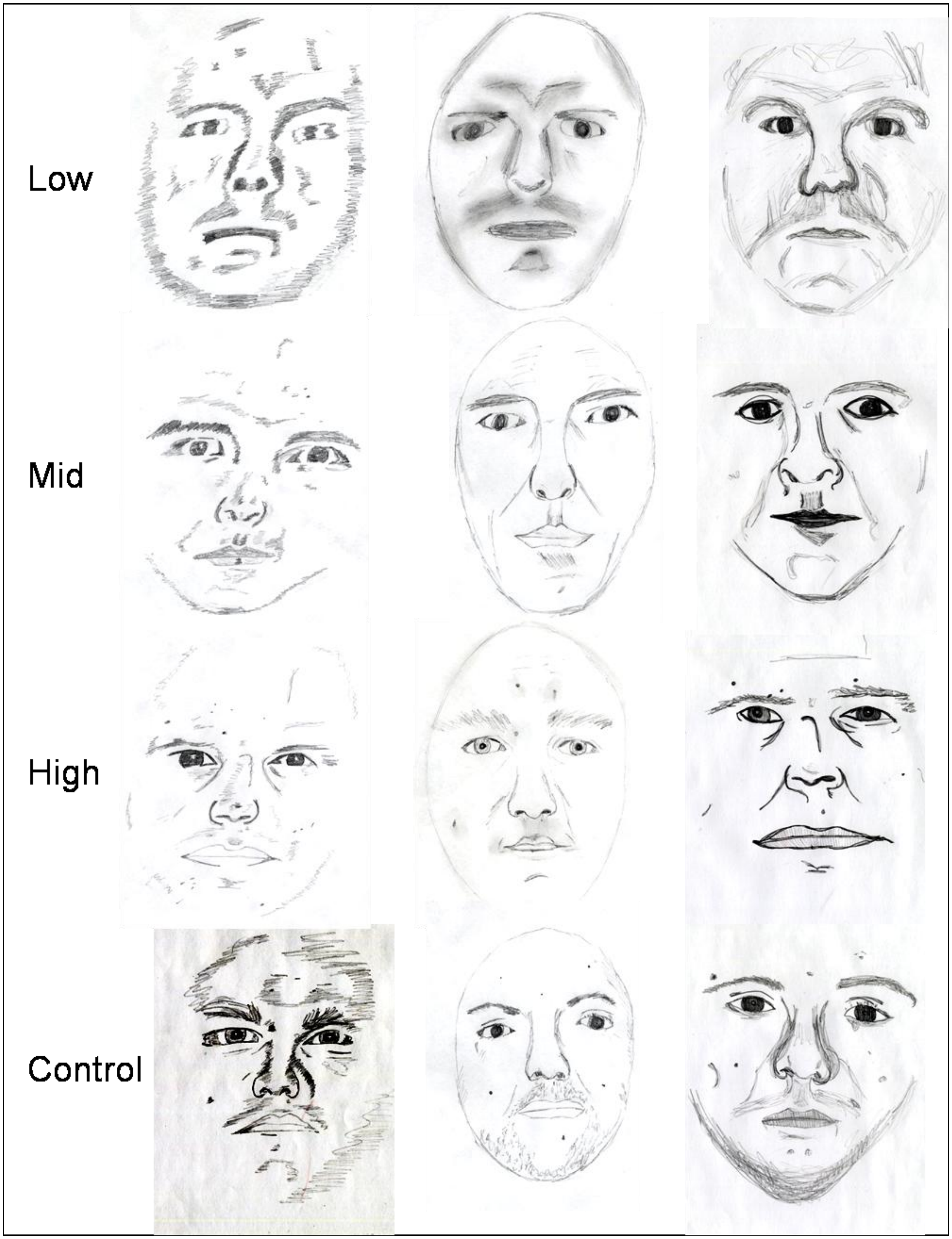


Figure 9. Example drawings obtained in the present study.

Low Spatial Frequencies

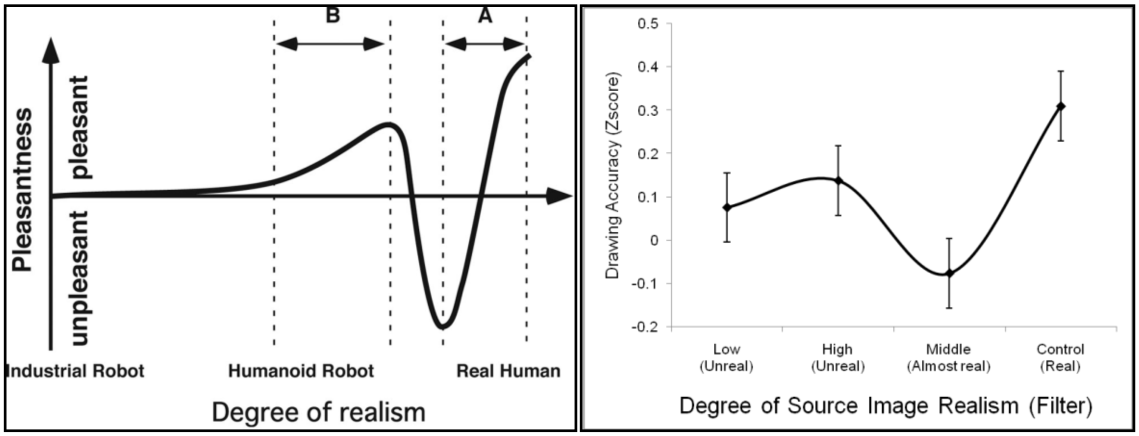
The LSF condition produced relatively accurate drawings in the present study. Consistent with hypothesis one, this result suggests that spatial configuration information is a critical component of accurate drawing. Because artists only had access to global information during the LSF condition and yet were still able to produce relatively accurate drawings, this result tells us that spatial configuration information is a large piece of the information that people are utilizing when drawing portraits. Furthermore, because the spatial configuration information is also available in the MSF condition but the MSF condition performed worse than the LSF condition, it appears that isolating the spatial configuration information from the information that is used for face recognition somehow facilitated more accurate drawing.

The issue of isolation is an interesting one and future research should examine differences in perceptual processes that result when spatial frequencies are isolated artificially. Although the difference between the LSF and MSF conditions lost statistical significance when the same drawings were compared to their source, this is likely due to the MSF drawings receiving higher ratings in this comparison condition and thus the result remains meaningful. Also recall that during the detection of facial expressions, LSFs are preferentially selected (Schyns & Oliva, 1999). Perhaps there exists a common mechanism between our results and the results from expression detection research.

When the LSF drawings were compared to their source image, they were rated significantly lower than the drawings that were produced in the HSF condition. This tells us that the novice artists had a harder time representing configural information (i.e., LSFs) than they did the edge and detail information (i.e., HSFs). Perhaps this is why art instruction frequently uses grids, overlaid on an image, to facilitate novice artists’ accurate representation of spatial configuration information whereas no similar technique exists for the rendering of edge and detail information. Furthermore, as their artistic skills and abilities increase, artists "grow out" of using such grid techniques. Perhaps this growth indicates that training increases the utility of LSFs more so than HSFs. If this were true, then if the current study were replicated using a sample of trained artists, we would expect to see larger increases in drawing accuracy (relative to the current results) in the LSF condition than in the HSF condition.

Middle Spatial Frequencies

The drawings in the MSF condition show a significant decline in accuracy relative to the other three conditions (e.g. LSFs, HSFs, & control). This dip in the data is an interesting and perplexing result. There are a couple of possible explanations for this dip, which are discussed in turn. One possible explanation is in terms of a phenomenon in the face perception and robotics literature known as the "uncanny valley" (Mori, 1970; Seyama & Nagayama, 2007). This refers to a dip in looking time data for human observers looking at artificial faces, and is a topic of interest for engineers developing faces for humanoid robots. This theory suggests that as a human likeness of a computer generated face increases, the likeness reaches a point where it stops being appealing and becomes eerie, based on minor inaccuracies of the "almost real" faces. Figure 10 presents the hypothetical uncanny valley representation from Seyama & Nagayama (2007) next to the data from the present study.



A **B**

Figure 10. The (A) Hypothetical Uncanny Valley's likeness to (B) the present data pattern. The resemblance is uncanny. Image A taken from Seyama & Nagayama (2007).

Recall that the band of spatial frequencies for the MSF condition was 8-16 c/fw. This is the optimal range for face recognition. This filter condition was the most "realistic" out of the three filtered conditions but less realistic than the control. Perhaps because the MSF faces were realistic but "not quite there" the artists had an uncomfortable reaction to the MSF condition and spent less time looking at the to-be-drawn image. If so, then that could explain the steep decline in drawing accuracy, since not looking back at the to-be-drawn stimulus would increase the working memory load of the visual spatial sketchpad. Holding the to-be-drawn image in working memory for longer periods of time would increase the chances of perceptual distortions stemming from top-down influences such as schematic facial representations.

To test the speculation that the uncanny valley may account for the relatively poor drawing performance in the MSF condition, 17 undergraduate students in the Sensation and Perception class at Kansas State University where asked to use an 11-point Likert-type scale to "rate the eeriness" of one of the faces used in our study at each of the four different filter levels[4].

[4] All of the participants indicated that they understood the concept of "eeriness."

This methodology is consistent with the methods of MacDorman et al. (2009) for measuring people's experience of artificial faces. Their results indicated no difference in eeriness between the four filter levels, thus failing to provide support for the uncanny valley as a valid explanation of our results.

A simpler explanation of the relatively poor performance in the MSF condition comes from differences in the task in which the participants are engaged. Our hypothesis that MSFs may exhibit an advantage for face drawing was based findings from the face recognition literature showing that a mid-ranged band of spatial frequencies from 8-16 c/fw optimally facilitated face recognition when faces were presented briefly (i.e. less than one second). In the current study, artists were asked to draw, not recognize, faces and they were allowed to view the face stimuli for 10 minutes. Thus, there is a large discrepancy between the current task and the task from which our second hypothesis was based. It is plausible that the length of time required to draw, and the complex nature of the act of drawing, change what SFs are utilized for percpetion of a to-be-drawn stimulus. For example, if artists use LSFs to capture global information and use HSFs to capture local information, the information carried byMSFs may become redundant for drawing. This may explain why, contrary to our second hypothesis, MSFs demonstrate little utility for drawing.

The present interpretation of the data suggests a real dissociation between face *recognition* and face *production*. An interesting test of this dissociation would be to compare the face recognition and face drawing abilities of trained and untrained artists. If there is a real dissociation between face recognition and face production, then the face recognition ability of highly trained portrait artists should not be significantly better than that of untrained artists.

High Spatial Frequencies

The accuracy ratings for the HSF condition differed significantly depending on whether the drawings were compared to the HSF source image or the unfiltered control. Because a significant difference in accuracy ratings based on comparison is only present for the HSF condition, it seems that artists were better able to accurately render a HSF image so that their end products actually looked like the HSF filtered photographs. The failure to observe comparison differences in accuracy ratings at the LSF and MSF filters suggests that something about the lower spatial frequency information is not as useful in drawing while some perceptual aspect of HSF is easier to render, such as the presence of edges and detail in the HSFs that are absent in the LSF and MSF filters. This suggests a real importance of edges for drawing. It appears that novice artists are tuned to render HSF information and use this information to render the edges of local facial features. Consistent with our predictions based on Biederman's (1983) Recognition-by-Components theory of object recognition and other theories of the utility of HSFs in object recognition (Schyns & Oliva, 1994, Marr & Hildreth, 1980), artists' reliance on edges may facilitate their drawing by allowing them to identify vertices and parse individual facial features accordingly. Perhaps parsing facial features allows the features to be perceptually isolated and subsequently rendered with greater accuracy.

All Spatial Frequencies (Control)

The control condition consistently produced more accurate drawings than any other condition regardless of what image (source or control) the drawings are being compared to. When considering this result in the context of the overall data pattern, an interesting interpretation presents itself. The data show that, in isolation, the LSF and HSF information is most useful for drawing relative to the MSF information. Three important points regarding these bands of spatial frequencies help to explain the overall better performance of the control condition. These are:

- LSFs carry information about the global structure of images useful for rendering accurate spatial configurations.
- HSFs carry edge and detail information useful for rendering individual facial features in detail.
- Both LSFs and HSFs are present in the control condition.

Considering these points, the increased accuracy of the control condition can be explained. In the control condition, artists had access to all spatial frequency information. This includes the LSFs that can be used to map global features and HSFs that can be used to render edges and detail. It seems that when granted access to all spatial frequencies, artists are capable of selecting out the spatial frequency information that is relevant for the drawing task in which they are engaged (e.g. defining edges of facial features or determining their spatial location) and therefore giving them all of the available information is beneficial to drawing accurately.

A simple explanation of this result is that if both LSFs and HSFs are useful and they are different and separate, then either is lacking in the other. In other words, in the LSF condition, useful HSF information is absent and vice versa. Thus, only the control condition has both and provides artists with a greater amount of useful information.

However, MSFs are also present in the control condition and even though this range of spatial frequencies has demonstrated a lack of utility for drawing, it does not appear to interfere with artists ability to render accurate images in the control condition as this condition produced the most accurate drawings overall. This suggests that when given access to all spatial frequencies, artists are able to focus their efforts on using LSFs and HSFs that appear to be more useful for drawing while somehow ignoring the MSFs that are useful for face recognition but redundant for drawing. A possible basis of this explanation, illustrated in Figure 11, is that the present study's data pattern exhibits an inverse relationship to the CSF—specifically, the frequencies that we are least sensitive to (e.g., LSFs and HSFs) are useful for drawing, while the spatial frequencies that we are most sensitive to (i.e., MSFs) demonstrate lower utility. What this means for drawing is that we discount the MSF information that is useful for face *recognition* and to which we are most sensitive in order to focus on acquiring the information to which we are less sensitive that is useful for drawing. This explanation is analogous to an explanation of the "horizontal effect" for natural images (Essock, DeFord, Hansen, & Sinai, 2003, Hansen, Essock, Zheng & DeFord, 2003). This research showed that during percpetion of naturalistic stimuli, people are more sensitive to oblique orientations and least sensitive to horizontal orientations. The authors argue that the prevalence of horizontal orientations in the environment (because virtually all outdoor scenes have a horizon) has influenced the development of the mammalian visual system to have an abundance of striate nuerons tuned to horizontal orientations (De Valois, Yund, & Hepler, 1982). Thus, Essock et al. (2003) attributed their findings to the visual system's discounting of the ubiquitous and redundant visual information, namely horizontal orientations, such that the information to which we are less sensitive (oblique orientations) becomes more salient and more useful for the task.[5]

Consistent with this explanation, Keil (2009) has provided evidence demonstrating that human faces contain a particularly high amount of MSFs (relative to LSFs and HSFs), just as natural scenes contain a great deal of horizontal orientations. The face recognition literature demonstrates that we are most sensitive to MSFs for recognizing faces (i.e. we are sensitive to

[5] In the case of Essock et al. (2003), their subjects' task was to adjust a test stimulus, a broad-band isotropic noise image, "to match the perceived strength or salience of the oriented [standard image](p. 1330)."

the information that is most available) (Boutet, et al., 2003; Braje, et al., 1995; Collin, et al., 2006; Costen, et al., 1996; Fiorentini, et al., 1983; Gold, et al., 1999; Nasanen, 1998; Parker & Costen, 1999; Sinha, 2002). Considering the findings of Essock et al. (2003), it seems that in the current study artists discounted the redundant MSFs in order to focus on the less available (but more useful) low and high spatial frequencies that carry configural and detail information respectively. Essock et al. observed that people suppressed highly available information when they presented their participants with naturalistic stimuli with structure similar to that encountered in the world, but not in similar tasks using simple sine wave gratings. Thus, the suppression of ubiquitous information seems to be dependent upon the stimuli. In face recognition studies, MSFs are most useful. Because MSFs are not useful for our drawing task, it seems as though the present results may be dependent upon the task. To describe this anisotropic sensitivity effect graphically, in Figure 11 I have plotted a hypothetical function of this discounted perceptual sensitivity to middle spatial frequencies against the original CSF.

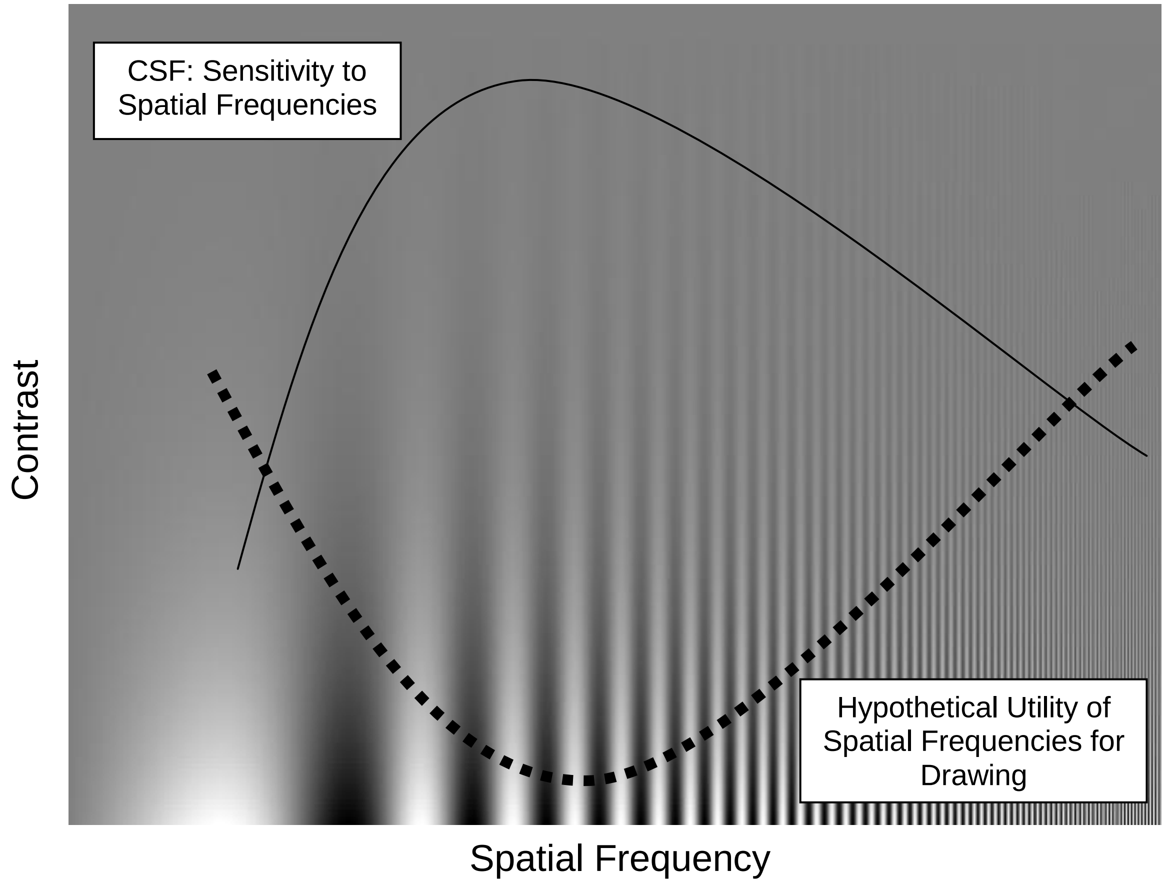


Figure 11. A hypothetical representation of artists' sensitivity to low, middle, and high spatial frequencies during drawing. The observed results indicate an inverse CSF such that what we are normally less sensitive to becomes more useful for drawing and the ubiquoutous MSFs are discounted and become less useful for drawing.

Because the data show that MSFs are not part of the useful information in the control condition (i.e., the information that MSFs provide is redundant), an additional hypothesis presents itself. If LSFs and HSFs are useful for drawing and MSFs do not provide any information that is beneficial to the drawing process, then if artists are provided with notch-passed images with only the MSFs removed, drawing performance should be equal to or greater than the present control condition. Additionally, because LSFs carry configural information and HSFs carry featural information, another informative test of the present interpretations would be to ask critics to rate the accuracy of the drawings based independently on configural accuracy and featural accuracy. Based on the interpretation of the present data, we would expect greater configural accuracy in the LSF condition and greater feature accuracy in the HSF condition. These are ready empirical questions for future drawing research.

Limitations

There are at least four *possible* limitations of the present study. First, the faces presented herein were presented for a total time of 10 minutes. This is an extremely long time in perception research. The face recognition studies cited above presented their band-passed faces on the order of 10's or 100's of milliseconds thereby tapping into low level perceptual processes that take place during the first moments of perception. This makes the interpretation of face drawing results difficult vis-à-vis with the face recognition literature. A possible solution to this problem would be to briefly present the images and have artists draw from memory. However, this would confound the effects of the perceptual processes involved in drawing with effects stemming from the limits of short term memory. Recall that Cohen (2005) posited that the longer imagery is held in working memory, the more susceptible it is to perceptual distortion. Thus, a better solution would be to present brief flashes of filtered images to artists as many times as they desire for up to 10 minutes. This is yet another worthy avenue of future drawing research.

On the other hand, the long presentation time of faces in the current study may not be a limitation at all. The current study was interested in evaluating drawing, which takes time. Therefore, if we do not interpret the present results in the context of the face recognition literature and interpret them as *drawing* results, the 10 minute presentation time of the faces buttresses the present study because we are learning about how novice artists utilize specific bands of spatial frequencies over long periods of time.

A second possible limitation of this study stems from the nature of the stimuli. The stimuli used are faces, and some researchers hold that faces receive special processing in the fusiform face area of the inferotemporal cortex (Kanwisher & McDermott, 1997). Thus, the findings from this study may or may not generalize to the rendering of other stimuli. However, learning more about face perception is a benefit inherent in the use of face stimuli and therefore reduces the impact of this possible limitation. Furthermore, the existence and role of the fusiform face area is a topic of current debate with some researchers holding that faces do not receive special processing (Gauthier, 2000) and that “the FFA may not be specific for faces per se, but rather only for the operations we typically, and by default, perform when perceiving faces (Gauthier & Tarr, 2002, p. 431).” Therefore, the use of faces in the present is not a *guaranteed* methodological limitation.

The third possible limitation of the proposed study is that any conclusions that are drawn regarding the perceptual processes involved in drawing are limited to the population of novices (i.e., untrained artists). Future research should investigate these processes with samples of trained artists so that similarities and differences between trained and untrained artists regarding the perceptual processes involved in drawing can be assessed. It is plausible that formal training in the visual arts will affect the strategies and processes utilized during drawing. For example, it is possible that LSFs are of more use to trained artists who are skilled at portraying accurate spatial relationships, a task for which novice artists may enlist the help of the aforementioned grid technique.

Then again, the use of untrained artists here can also be interpreted as a strength of the study. The majority of people are not professional artists and because most individuals lack formal training in the visual arts, the present study speaks to how *most* people and *new* art students utilize specific bands of spatial frequencies for drawing. The use of untrained artists therefore increases the utility of these findings for informing art instruction.

Finally, there exists some disagreement in the literature regarding the equality edges and HSFs. This disagreement has implications for the theoretical bases for our hypotheses. Biederman and Ju's (1988) claim that edges are sufficient for object recognition was based on the use of simple line drawing stimuli. However, Sanocki et al. (1998) found that, while a photographed object is readily identified when presented in the form of a line drawing, the same object is less recognizable when presented as an "edge image" produced by a computer-based edge extraction algorithm applied to the same photograph. Figure 12 demonstrates the differences between these types of images by presenting A) an original photograph, B) a simple line drawing of the photograph and, C) an edge image based on an edge extraction algorithm applied to the photograph. These true edge extracted images are much different (and more visually complex) than the simple line drawing stimuli used by Biederman and Ju (1988). Thus, questions remain regarding the validity of Biederman and Ju's claims regarding the importance of edges as there edges are different than those carried by HSFs. Furthermore, it is unclear whether the findings from object recognition research scale up to the context of drawing. However, importantly for the present study, Marr and Hildreth (1980) state that edges, which I propose are critical for drawing, are carried in HSFs that were presented to our artists. Therefore, *the present* conclusions regarding the utility of edges in drawing are well founded.

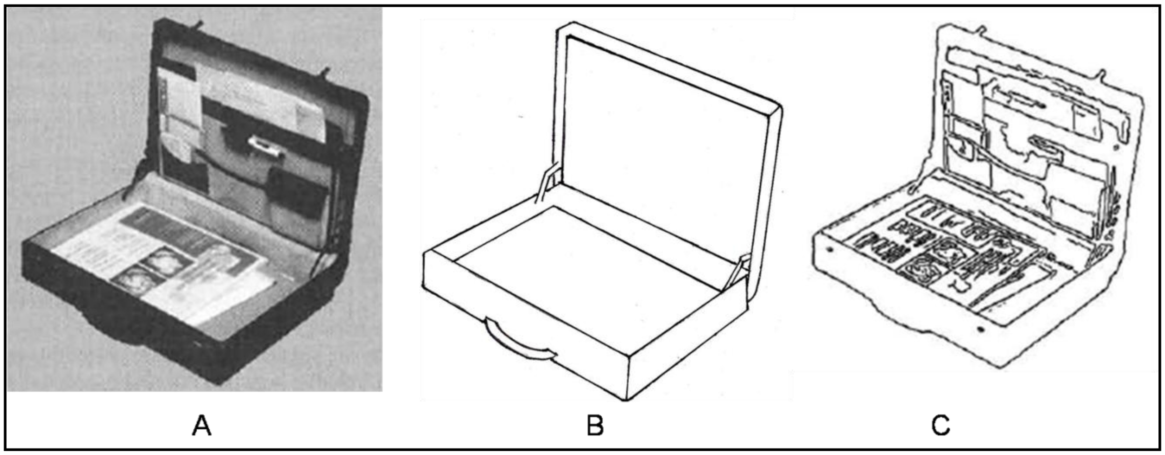


Figure 12. The original source image is presented in (A). Compare Biederman's line drawing type images (B) to Sanocki et al. edge images achieved using the Canny (1986) edge detector (C). The Canny detector locates more edges and the resulting image is more complex.

Implications

The present data support our position that the different bands of spatial frequencies are perceptually different in a way that is meaningful for the drawing process. Future research should investigate potential sources of the poor performance of the MSFs relative to LSFs and HSFs. The data's sharp contrast with the hypothetical CSF suggests a logical starting point. The plausability of people's inversion of the CSF as an explanation of the present data pattern should be tested.

This study was the logical next step to answering the unanswered questions from the Freeman and Loschky pilot study. Specifically, it begins to tease apart the differences between the utility of the HSFs, MSFs and, LSFs in the context of the drawing procedure. Additionally, because the artists only had access to one band of spatial frequencies at a time, the results indicate the relative utility of each. Future analyses may include comparisons of the pilot data from Freeman and Loschky with the data collected in the current study. Because the present HSF condition, in which artists are presented with only HSFs for the whole drawing time, produced more accurate drawings than the LSF and MSF conditions, it seems that a longer duration of access to the HSFs is beneficial to drawing. Furthermore, because being presented with HSFs for the full ten minutes of drawing time produced more accurate drawings than the LSFs and MSFs, the data suggest that HSFs are rich in information that is useful for the rendering of faces (Goffaux et al, 2005). Through the isolation of LSFs and HSFs, this research also speaks to the unique importance of global and local information in the context of the drawing procedure. As such, it is a novel contribution to the study of perception and drawing.

There is much to be achieved from this line of research. Gaining an understanding of the low-level perceptual processes involved in the creation and evaluation of art will allow us to inform art instruction in schools and perhaps improve the conventional methods used for teaching drawing. Art instructors take many different approaches to teaching students the fundamentals of drawing. If research is able to establish an understanding of the low-level processes involved in drawing, it is possible that general art instruction could be altered to reflect that understanding. For example, because LSFs performed relatively well, that could inform art students to focus on the LSFs and global composition (perhaps by squinting their eyes) to obtain an accurate spatial layout of the to-be-drawn object and then refine those features by focusing on the details conveyed in HSFs. Additionally, because the drawings produced in the HSF drawing condition also perform well, the importance of objects' edges for drawing is highlighted. Gaining an understanding of the criticality of essential edges for drawing would be beneficial to psychologists studying the perceptual processes involved in drawing and would contribute novel and useful information to such research endeavors.

Appreciation of the information most useful for accurate drawing may also allow us to further develop drawing technology. This would include software applications such as the Microsoft® application "Paint" as well as the development of electronic drawing tablets that are commonly used in graphic design and CAD work. There is a lot of room for improvement of these programs and they may be advanced with the acquisition of an understanding of the complex motor, perceptual, decision making, and evaluative processes that are involved in being able to accurately render an image. For example, if different bands of spatial frequencies appear to be optimal for different tasks then the software that accompanies drawing tablets could include a spatial filtering application so that users can isolate spatial frequencies contingent upon the task in which they are currently involved (e.g., LSFs for spatial layout of images and HSFs for refinement and detail).

More importantly, understanding drawing at both a perceptual and a cognitive level will allow us to develop and utilize drawing as a tool for perceptual and cognitive assessment. Drawing may be used to assess motor skills, decision making processes, and perception. Drawing has already proved to be especially useful for evaluating perception in human subjects with perceptual deficits such as visual neglect or visual agnosia (Marshall & Halligan, 2004; Rubens & Benson, 1971; Shulman, 2000). Additional insight could be gained from studies like these if we possessed a richer understanding of the low level perceptual processes that play a role in the drawing process.

Perception research can be greatly furthered through the study of the low level perceptual processes involved in the art. For example, in Arnheim's (1974) book titled, *Art and Visual Perception*, he covers perceptual properties of objects such as balance, shape, and form as well as their importance in the creation and evaluation of art. These are perceptual principles that are available to conscious perception; however, low level perceptual phenomena such as the role of spatial vision during artistic rendering of objects remains unexplored. To that end, this line of research is an original and novel attempt to begin the advancement of drawing research.

Additionally, if we gain a working knowledge of the perceptual processes involved in creating art, we may be able to develop working theories of drawing grounded in the principles of low level perception. Cohen and Bennett (1997) stated that perception of to-be-drawn stimuli is perhaps the most significant cognitive contribution to peoples' ability to draw accurately. To expand on their observation and develop working theories of the perceptual processes involved in stimulus perception during drawing, it is important to develop a program of research aimed at assessing these processes through the lens of low level perception. The present research is aimed at facilitating the development of such a research program by investigating the role of spatial vision in the perception of the to-be-drawn stimulus during drawing.

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