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Low and High Spatial Frequencies Are Most Useful for Drawing

Tyler E. Freeman and Lester C. Loschky
Kansas State University

What perceptual information do artists use to accurately render what they see? To answer this question, we investigated the utility of low, middle, and high spatial frequency bands for drawing. Untrained artists drew portraits from four spatial frequency bands (unfiltered, low, middle, and high). Raters judged the accuracy of those drawings compared to images of either the same or an unfiltered version of the face. Contrary to predictions based on the useful spatial frequencies for face recognition, which favor middle spatial frequencies (MSFs), the results showed that low spatial frequencies (LSFs) and high spatial frequencies (HSFs) were more useful for drawing, and the unfiltered condition produced the best drawings. Thus, the information most useful for drawing faces is not the same as that for recognizing faces. Specifically, artists may utilize the global configuration information carried in LSFs and the edge and detail information carried in HSFs to render accurate drawings.

Keywords: art, drawing, face perception, face recognition, spatial vision

Drawing is a window into the perceptual world of the artist, and as such has great potential as an evaluative tool for studying perception (Fish & Scrivner, 1990; Frith & Law, 1995; Kozbelt, 2001; Mitchell, Ropar, Ackroyd, & Rajendren, 2005; Marshall & Haligan, 2004; Rubens & Benson, 1971; Shulman, 2000; Solso, 2001; Van Sommers, 1984). However, in order to use drawing to evaluate perception, we must first understand the underlying perceptual, cognitive, and motor processes that allow people to accurately draw what they see.

Cohen and Bennett (1997) investigated multiple factors hypothesized to affect one's ability to accurately render images, and concluded that one's perception of the to-be-drawn stimulus is most important. In addition, several studies investigating the role of eye movements in drawing (Cohen, 2005; Gowen & Miall, 2006; Miall & Tchalenko, 2001; Tchalenko, 2007; Tchalenko & Miall, 2008) suggest that the less time that visual information is held in working memory, the less susceptible it is to perceptual distortions, further supporting the importance of perceptual processes in drawing.

To better understand the perceptual processes involved in the drawing process, the current study focuses on perception of the stimulus during drawing using a novel approach based on well-founded principles of spatial vision dealing with low-level perception. To our knowledge, no previous studies of the drawing process have incorporated theory and methods from spatial vision to investigate the low-level perceptual processes involved during complex reproduction tasks (i.e., drawing). We, therefore, include a brief discussion of the spatial vision literature and its relevance for the current research effort.

Tyler E. Freeman and Lester C. Loschky, Department of Psychology, Kansas State University.

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Correspondence concerning this article should be addressed to Tyler E. Freeman, Department of Psychology, Kansas State University, Manhattan, KS 66502. E-mail: tylerf@ksu.edu

Different Spatial Frequencies Have Different Perceptual Uses

Research in spatial vision suggests that our visual system utilizes *spatial frequency channels*, which differentially process visual information carried in specific bands of spatial frequencies (Campbell & Robson, 1968; DeValois & DeValois, 1980; De Valois, Yund, & Hepler, 1982; Schyns & Oliva, 1994; Vassilev & Stomonyakov, 1987). The term "spatial frequency" (SF) is a measurement of the number of cycles of a sine wave in a given unit of space, and in the study of visual perception, SFs are often used as a means of measuring the limits of the visual system. SFs can be described as groups of frequencies termed "bands," and different SF bands convey specific information about the appearance of a stimulus. For example, bands of higher SFs (HSFs) typically convey edge information and fine detail of a stimulus whereas bands of lower SFs (LSFs) carry information regarding the global structure of a stimulus.

Researchers must apply spatial filters to images in order to isolate narrower bands of frequencies because normal images contain a broad band of spatial frequencies. Spatial filters can be implemented using computer algorithms that isolate the 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 cortical area V1 tuned to be sensitive to specific bands of spatial frequencies (De Valois & De Valois, 1980).

How the human visual system uses various bands of SF information has been shown to be affected by task demands. For example, when Schyns and Oliva (1999) asked participants to identify whether or not a face was emotionally expressive, people tended to utilize LSFs but, when they were asked to categorize the specific emotional expression (happy or angry) they relied on

HSFs. Thus, for the task of drawing a face, it is plausible that a particular range of SFs that are preferentially utilized.

Similarly, research has shown that processing of faces at the configural (i.e., face as a whole) versus featural (i.e., feature by feature) levels is differentially influenced by LSFs and HSFs respectively (Goffaux, Hault, Michel, Vuong, & Rossion, 2005). Therefore, if drawing portraits relies more upon either configural or featural processing, we may see an advantage for either LSF or HSF bands respectively. However, drawing portraits likely requires both configural and featural processing. If this truly is the case, we would expect to see the best drawings produced when artists have access to, and draw, using both LSFs and HSFs.

A related topic in the face recognition literature concerns humans' use of SF information when attempting to recognize and/or identify faces. In these studies, subjects are typically shown briefly presented face stimuli that have been band-pass filtered (e.g., they have removed HSFs and/or LSFs) to allow the viewers access to only limited information (e.g., global or local). After brief presentations of the band-passed faces, viewers are typically asked to discriminate the test faces from a set of standard images (Boutet, Collin, Faubert, 2003; Collin, Therrien, & Martin, 2006; Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983; Gold, Benett, & Sekuler, 1999; Näsänen, 1998; Parker & Costen, 1999). Using this methodology, these studies have consistently shown that a specific, one-octave-wide middle SF (MSF) band (approximately 8–16 cycles per face width (c/fw) is optimal for face recognition tasks. Because this band of MSFs is optimal for face recognition, we have a theoretical basis to predict an advantage for MSFs in face drawing.

Needless to say, the time course of the effects reported in the face recognition literature is much shorter than that of drawing faces. Nevertheless, these results suggest that if the SFs that are most useful for recognizing faces are the same as those that are most useful for drawing them, we should see greater drawing accuracy when artists are presented with faces band-pass filtered to contain primarily MSFs. In support of this notion, Keil (2009) has shown that faces are rich in MSFs. Therefore, if artists simply use the information that is most available to render faces, then we should see an advantage for the MSF condition.

Because a large body of spatial vision research has investigated face recognition, and because portraiture is a very common practice in drawing, a natural way of applying findings from spatial vision to investigating drawing processes would be to have artists draw portraits from band-pass filtered faces.

Drawing Recognizable Faces and Objects

Marr and Hildreth's (1980) theory of object recognition suggests that an object's principal edges are carried by its HSFs and, that people use that information for object recognition. Their seminal theory highlights the importance of edges for our perception of distinct objects. This makes sense considering that the mammalian visual system is designed to process edges (Hubel & Wiesel, 1959) and uses these edges to organize recognized objects in the environment (Peterson & Gibson, 1994).

Biederman's (1987) Recognition-by-Components (RBC) theory of object recognition, which is based, in part, on the work of Marr and Hildreth (1980), suggests additional hypotheses regarding the utility of HSFs for drawing. According to RBC theory (Biederman, 1987), edge information allows one to extract individual geometric primitives of an object, called geons, and thereby recognize objects accurately. Consistent with this, Biederman and Ju (1988), asking subjects to name or verify common objects (against target names), demonstrated the importance of edges for object recognition. They showed that object recognition is possible in <100 ms using only line-drawn edges of objects. They concluded that, "A simple line drawing can be identified about as quickly and as accurately as a fully-detailed, textured, colored photographic image of that same object" (p. 63).

Because the goal of drawing in the current study is to render a recognizable object, and objects can be recognized solely through their edges (Biederman & Ju, 1988), which are carried in HSFs (Marr & Hildreth, 1980), it is plausible that novice artists rely on HSFs to extract edges and reproduce recognizable structures (here facial features). Thus, although the above research used tasks different than drawing, their contributions provide a theoretical rationale for predicting an advantage of HSFs in drawing.

A second, admittedly less theoretical, reason to expect an increased utility of HSFs for drawing comes from naturalistic observations of the common drawing practices of artists and nonartists alike, in which people outline objects' edges (conveyed in HSFs) and then fill in with shading (conveyed in MSFs and LSFs). Such practices suggest that, edges are important during drawing. Indeed, the 19th century French artist, Eugéne Delacroix, wrote in his personal journal that when drawing an object, one should start by rendering its principal lines (i.e., edges; Delacroix, 1938) consistent with the hypothesis that drawing relies (at least in part) on HSFs.

Hypotheses Regarding the Utility of MSFs, HSFs, and LSFs for Drawing

In order for a portrait to be judged as accurate, the individual facial features must be drawn accurately, and arranged in the correct spatial configuration. Based on our review of the literature, we will now outline our predictions as to why particular bands of SFs may differentially facilitate success in each of these dimensions.

MSFs. Spatial vision studies of face recognition have shown that people preferentially use a MSF band of around 8–16 c/fw to recognize faces (Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983; Gold, Bennett, & Sekuler, 1999; Näsänen, 1998; Parker & Costen, 1999). Furthermore, faces contain a wealth of MSFs making them highly available for processing by the visual system (Keil, 2009). Together, the above research suggests the hypothesis that MSFs are optimal for drawing faces. This hypothesis is based on the assumption that face recognition plays a critical role in face drawing, and if the hypothesis is true, it would suggest that the two processes use similar SF information.

HSFs. Research suggests that the mammalian visual cortex is designed to process edges (Hubel & Wiesel, 1959), which are carried by HSFs. Furthermore, Biederman's (1987) influential theory of object recognition emphasizes the importance of perceiving edges, particularly the vertices that make up the geometric primitives of objects. Therefore, if the goal of representational drawing is to convey recognizable objects, and if this requires rendering their vertices, then it would suggest the alternative hypothesis that HSFs are particularly useful for drawing (Biederman, 1987; Biederman & Ju, 1988; Hubel & Wiesel, 1959; Marr & Hildreth, 1980; Peterson & Gibson, 1994). This hypothesis is further bolstered by naturalistic observations of the common drawing practices of both artists and non-artists.

LSFs. As can be seen in Figure 1, the LSF faces lack all detail and edge information, but their spatial structure remains (Goffaux et al., 2005). Because producing the proper spatial configuration of constituent features is critical for accurate drawing, artists may rely on LSF for success in this dimension. Additionally, LSFs should also be useful for rendering large areas of highlight and shadow which can factor into observers' judgments of drawing accuracy. These observations suggest the alternative hypothesis that LSFs are especially useful for drawing.

All spatial frequencies. Given the above stated hypotheses, each of which argues for the importance of a different SF band for drawing, a simple hypothesis is that, for drawing, more information is better. More specifically, an unfiltered control condition, containing a broad band of SFs, would produce better drawings than any other narrower bands.

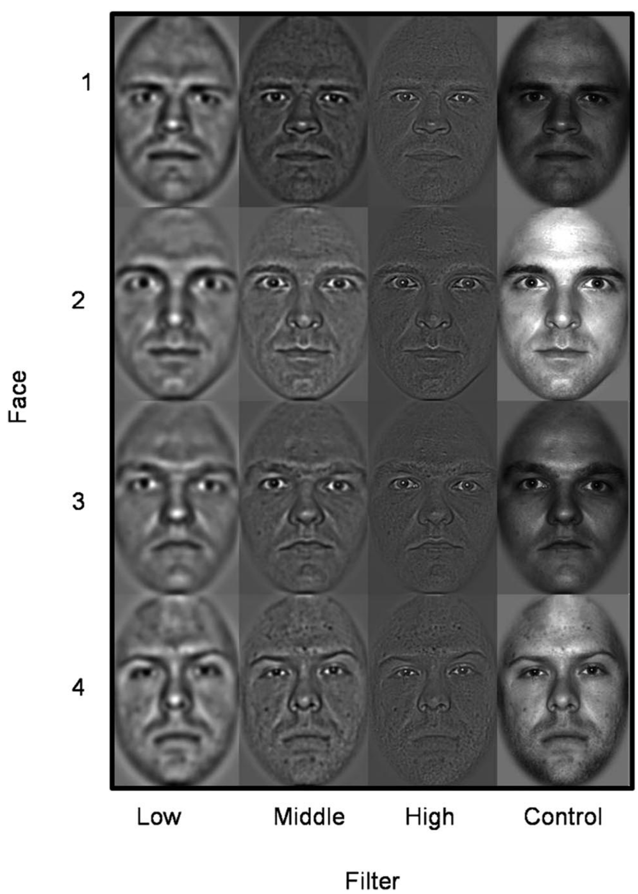

Figure 1. The stimuli used in the current study. The "Low" column contains faces filtered to contain a one-octave wide band of spatial frequencies ranging from 4–8 c/fw. The "Middle" column contains faces filtered to contain a one-octave-wide band of SFs ranging from 8–16 c/fw. The "High" column contains faces filtered to contain a one-octave wide band of SFs ranging from 16–32 c/fw. The "Control" column contains unfiltered faces.

Conversely, if utilizing a particular band of SFs is beneficial to drawing, it would suggest the hypothesis that the control condition would perform worse than one or more of the other bands (MSF, HSF, or LSF) because the control condition would contain the full SF spectrum and one band of SFs can interfere with the perception of another (Schyns & Oliva, 1994).

Method

Participants

Artists. All participants who produced drawings are referred to herein as artists. Ten undergraduate students from Kansas State University were recruited as novice artists (7 female, Age: $M = 20.3$, $SD = 5.2$). Consistent with past drawing research, our 10 artists had no formal training in the visual arts (Cohen & Bennett, 1997).

Raters. All participants who judged the accuracy of drawings are referred to herein as raters. Sixty-three undergraduate students from Kansas State University, with no formal training in the visual arts were recruited as novice raters (40 female, Age: $M = 18.8$, $SD = 1.4$).

Stimuli

Artists. Four male faces were band-pass filtered at four levels (4–8 c/fw, 8–16 c/fw, 16–32 c/fw and unfiltered) and served as the to-be-drawn LSF, MSF, HSF and control images respectively (see Figure 1). At an average viewing distance[1] of 42 cm, the images subtended approximately 12.25 (width) $\times$ 17.65 (height) degrees of visual angle.

Raters. Digitized scans of the drawings produced by the artists served as the raters' to-be-judged stimuli. The drawings appeared next to their respective comparison images.

Experimental Setup

Artists. The to-be-drawn images were presented on 17" CRT monitors. The artists were given 8.5" $\times$ 11" white typing paper fixed to a stationary clipboard to provide a stable and uniform drawing surface, and a sharpened number two pencil with an eraser. The artists were encouraged to keep the clipboard within a boundary outlined on their desk.

Raters. As shown in Figure 2, digitized scans of drawings from part one of the experiment were presented on the monitor, adjacent to either a) the source image (e.g., 4–8 c/fw, 8–16 c/ fw, 16–32 c/fw, or unfiltered control) from which the drawing was rendered, or b) an unfiltered version of the same face, depending on the rater's task (see Figure 2).

Procedure

Artists. The artists were seated at a computer and their instructions were presented on the monitor. Every artist drew each

[1] Viewing distance was not fixed in order to allow our artists to draw comfortably.

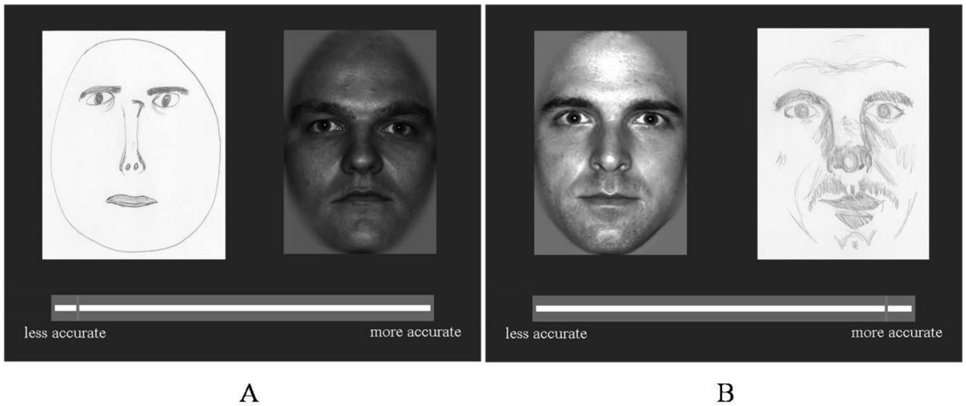

Figure 2. Example screen shots of the raters' task. The drawings were presented adjacent to either the original filtered face from which they were drawn or the unfiltered version of the same face. These images demonstrate A) an appropriate rating of a poorly done drawing, and B) an appropriate rating of a well done drawing. These were the lowest rated (A) and highest rated (B) drawings from a pilot study.

face once from a different condition, for a total of four drawings per artist. The pairing of faces and filter conditions was randomized, with the constraint that each face and each filter condition appeared once per artist. Each image was presented, and drawn, for 10 minutes.

Raters. All procedures were the same as above except as follows. At the start of the experiment, raters were given instructions on the monitor for how to judge drawing accuracy, which was operationally defined as a "true-to-life representational image." Figure 2 shows handouts that were given to the raters, showing screenshots of example experiment screens illustrating appropriate ratings for a poorly done and an extremely well done drawing (the lowest and highest rated drawings from a pilot study). This was done to a) prevent a floor effect as none of our artists had formal drawing training, and b) to increase rating variability by encouraging use of the entire scale (Marks & Gescheider, 2002). These example drawings gave raters a realistic idea of the level of drawing accuracy they would see. The raters used the computer mouse to manipulate a 100 point sliding scale, from 0 (least accurate) to 100 (most accurate) as shown in Figure 2. Raters made a total of 70 ratings each ([10 artists × 4 drawings × 2 ratings] – [10 redundant control drawings]).

Raters judged each drawing twice, once in comparison to the same filtered image from which they were rendered and, once in comparison to the unfiltered version of that face. For the drawings produced in the control condition, these two comparisons are redundant. Therefore, the drawings produced in the control condition were only rated once. The order in which these comparisons were made was randomized. The relative screen position at which the drawing or source image appeared (either left or right) was randomized and counter balanced.

This procedure allowed us to ask a) how well were artists able to draw the SFs they were given and, b) how well did that information allow them to render images as they would normally appear? Regarding the first comparison, if a highly skilled artist followed her instructions and only drew exactly what she saw, her drawings would look just like the filtered images—for example, a drawing from an LSF band-pass filtered face would look blurry and out of focus. If so, then if the raters evaluated the accuracy of her drawings compared to the original unfiltered images, she would be penalized for accurately drawing what she was given. Thus, it was necessary to obtain ratings of accuracy as compared to the same images from which they were drawn. Nevertheless, ratings in comparison with the original unfiltered images were also needed, in order to draw conclusions regarding the utility of the MSF, HSF, and LSF bands for drawing objects (here, faces) as they exist in the world. Assuming that the artists actually drew what they saw, and that the raters understood their task, this dual comparison methodology suggests one additional hypothesis. Specifically, accuracy ratings should be higher when raters compare the drawings to their source images than when they are compared to the original unfiltered images.[2]

Results

Prior to analysis, all accuracy ratings were normalized to each rater's range by creating within-subject *z*-scores for each rating. Because different raters may be biased to use different portions of the rating scale, with some being very harsh critics, others being very lenient, and still others using the full range, this procedure was employed to factor out between-rater variability in the range of the scale used, as in previous drawing research (Cohen & Jones, 2008, p. 12).

The mean correlation of all the rater's ratings, $r = .312$, as well as the Spearman-Brown effective reliability, $R_{SB} = .966$, which is a correction of the correlation coefficient that takes into account the number of raters (Harrigan, Rosenthal, & Scherer, 2005), indicated acceptable inter-rater agreement when drawings were compared to the source image from which they were drawn and

[2] Except for the drawing produced in the control condition, for which both comparisons are the same.

also when they were compared to the original unfiltered image, $r = .306$, $R_{SB} = .965$.[3]

An error in the experimental run-time program for the raters resulted in unbalanced image presentations for artists six and seven such that artist six received no ratings for their drawing from the LSF condition while artist seven received twice the normal amount of ratings for their control condition drawing. Thus, all ratings for artists six and seven were removed from the analyses. Later analyses showed that removal of these drawings did not substantively change the overall pattern of results.

The normalized rating data were collapsed on filter condition such that each rater had a mean rating for each of the four filters. Thus, the dependent variable was the mean normalized ratings assigned to each of the conditions. 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 rendered 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). We, therefore, decided to have a larger number of raters than artists, and thus to treat raters as the "subjects" in our within-subjects design. 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. The acceptable inter-rater agreement produced by the raters confirms that this strategy worked as intended. Furthermore, analyzing mean ratings for each rater as the primary dependent variable, and treating raters as the subjects in a within-subjects design has been done in previous drawing research (Cohen & Bennett, 1997).

These data were analyzed separately based on whether the drawings were compared to the source image from which they were drawn or to the unfiltered version of that face. The results are presented graphically in Figure 3.

Comparisons to the Source Image

Effects of filtering. Using the normalized rating data, we ran a one-way repeated measures ANOVA to test for the main effect of filter condition (LSF, MSF, HSF, and control) on rated accuracy when drawings were compared to their source image. The normalized means and standard deviations of the ratings from each of the four filter conditions are presented in Table 1. As shown in Figure 3, filter condition had a significant main effect on rated accuracy, $F(3, 186) = 18.867$, $p < .001$, Cohen's $f = .46$.

Multiple comparisons were carried out using Bonferroni corrected t tests and effect sizes were calculated using Cohen's d.[4]

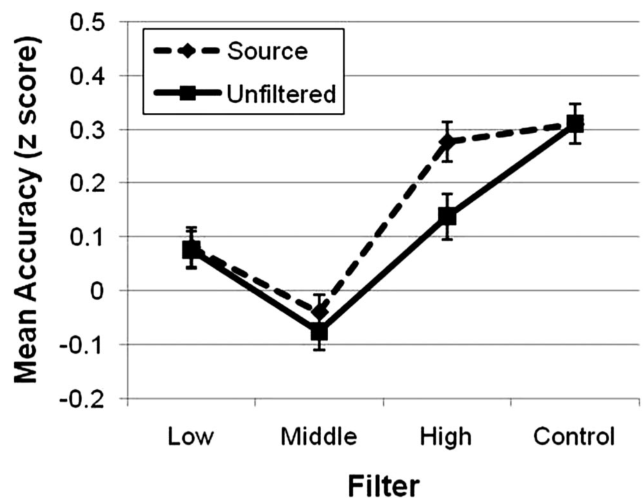

Figure 3. A comparison of the mean accuracy ratings in each filter condition for drawings compared to the source and control images. Error bars represent SEM.

The Bonferroni t-tests showed that drawings produced in the HSF condition were rated as significantly more accurate than those drawn in either the LSF, $p = .002$, $d = .666$, or MSF, $p < .001$, $d = 1.162$, conditions, as were drawings produced in the control condition compared to those in the LSF condition, $p = .001$, $d = .781$, and MSF, $d = 1.288$, conditions. However, there was no significant difference between drawings in the LSF and MSF conditions, $p = .141$, $d = .442$, or between the drawings in the HSF and control conditions, $p = 1$, $d = .113$.

The fact that the drawings produced in the HSF condition were rated as more accurate than those from either the LSF or MSF conditions is consistent with the hypothesis that edges are more useful for drawing than the global configural information carried in LSFs. Further, the fact that the HSF condition greatly outperforms the MSF condition is consistent with the idea that the information used to recognize faces is separate from the information used to draw them. The advantage of the control condition indicates that a combination of different SF bands is beneficial for drawing.

Comparisons to the Unfiltered Image

Effects of filtering. Again, using the normalized rating data, we carried out a one-way repeated measures ANOVA to test for the main effect of filter condition (LSF, MSF, HSF, and control) on rated accuracy when drawings were compared to the original unfiltered image. The normalized means and standard deviations

[3] The mean correlations (r) are the average of all pairwise correlations for each comparison. Using these values, and $n = 63$, the Spearman-Brown effective reliability was calculated for each comparison using the equation $R_{SB} = nr/1 + (n - 1)r$.

[4] The reported p values are taken from the Bonferroni corrected tests and are based on 95% confidence intervals. Effect sizes calculated using Cohen's d are interpreted as follows: Small = .20; Medium = .50; Large = .80 (Cohen, 1992).

Table 1
Means and SDs for Ratings of Drawing Accuracy by Filter and Comparison Image

	Source		Unfiltered	
Filter	Mean (z)	*SD*	Mean (z)	*SD*
LSF	.081	.295	.076	.279
MSF	−.04	.25	−.076	.28
HSF	.277	.293	.138	.331
Unfiltered	.309	.291	.309	.291

Note. Source = drawings compared to original filtered image; Unfiltered = drawings compared to unfiltered control image.

of the ratings from each filter condition are presented in Table 1. As suggested by Figure 3, there was a significant main effect of filter when drawing accuracy was compared to the unfiltered image, $F(3, 186) = 15.573$, $p < .001$, Cohen's $f = .42$.

Multiple comparisons were carried out using Bonferroni corrected *t* tests and effect sizes were calculated using Cohen's *d*. Multiple comparisons showed very similar results to those discussed above (when comparing drawings with their source images), with the key difference being the comparisons of the HSF condition with the LSF and Control conditions. Specifically, the LSF condition allowed for more accurate drawings than the MSF condition, $p = .03$, $d = .54$, as did the HSF condition, $p = .005$, $d = .70$. The drawings produced in the LSF condition were judged as comparable to those produced in the HSF condition, $p = 1$, $d = .203$. Importantly, the drawings rendered in the control condition received significantly higher ratings of accuracy than the LSF, $p = .001$, $d = 1.35$, MSF, $p < .001$, $d = 1.35$, and HSF, $p = .019$, $d = .55$, conditions.

The equality of LSFs and HSFs when drawings were compared to unfiltered images suggests that they are both important for rendering naturalistic faces. Additionally, because the control condition produced the best drawings, these results suggest that access to both LSFs and HSFs allowed our artists to more accurately render naturalistic faces in the control condition.

Effects of Comparison

Consistent with our prediction, as suggested by Figure 3 and the above analyses, a one-way repeated measures ANOVA showed a significant main effect of comparison image on rated accuracy, $F(1, 62) = 5.149$, $p = .027$, such that drawings were rated more highly when compared to their source image. However, this effect was relatively small, Cohen's $f = .181$. As shown in Figure 3, an independent samples *t* test showed that this effect is limited to the HSF condition, $t(1, 124) = 2.489$, $p = .014$, in which drawings were rated as more accurate when they were compared to their source image than when compared to the unfiltered image. This suggests that people are more adept at perceiving and rendering edge information from a HSF image than rendering information from MSF or LSF images. Nevertheless, the drawings rendered from HSF images look no more like the original unfiltered images than do the drawings from the LSF images.

Discussion

A sample of the drawings produced in this experiment can be seen in Figure 4 organized by the filter condition from which they were produced.

The results show that drawings were rated as more accurate when compared against the source image they were drawn from, but only for the HSF condition. Furthermore, the HSF condition produced greater accuracy than the LSF condition, but only when compared against the source image. This suggests that artists were better able to utilize the edges contained in HSFs than the configural information contained in LSFs. Such results are consistent with our predictions based on theories of object recognition that emphasize the importance of edges for object recognition (Biederman, 1987; Biederman & Ju, 1988; Marr & Hildreth, 1980; Schyns & Oliva, 1994). Thus, artists' reliance on HSFs may facilitate their drawing by allowing them to identify vertices, parse individual facial features, and subsequently render them with greater accuracy.

The LSF condition produced more accurate drawings than the MSF condition regardless of comparison image (source or unfiltered). This result is consistent with the hypothesis that LSFs facilitate rendering of spatial configuration information that is important for accurate drawing (Goffaux et al., 2005). Furthermore, because such spatial configuration information is also available in the MSF condition, yet the MSF condition produced less accurate drawings than the LSF condition, it suggests that isolating that spatial configuration information from the information used for face recognition (i.e., the MSFs; Boutet, Collin, Faubert, 2003; Collin, Therrien, & Martin, 2006; Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983; Gold, Bennett, & Sekuler, 1999; Näsänen, 1998; Parker & Costen, 1999) somehow facilitated more accurate drawing.

Nevertheless, when drawings were compared to their *source* (i.e., filtered) images, the LSF drawings were judged as less accurate than those drawings produced in the HSF condition. This suggests that when rendering an image, novice artists have more difficulty using configural information than using edge and detail information. 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 experience and training increases the utility of LSFs more so than HSFs. If so, 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, when drawings are compared to the filtered (LSF and HSF) source images.

We had hypothesized that MSFs might be particularly useful for drawing faces based on findings from the face recognition literature showing that a mid-ranged band of SFs around 8–16 c/fw optimally facilitate face recognition (with such faces usually presented for <1 sec, Boutet, Collin, Faubert, 2003; Collin, Therrien, & Martin, 2006; Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983; Gold, Bennett, & Sekuler, 1999; Näsänen, 1998; Parker & Costen, 1999). Contrary to this hypothesis, drawings in

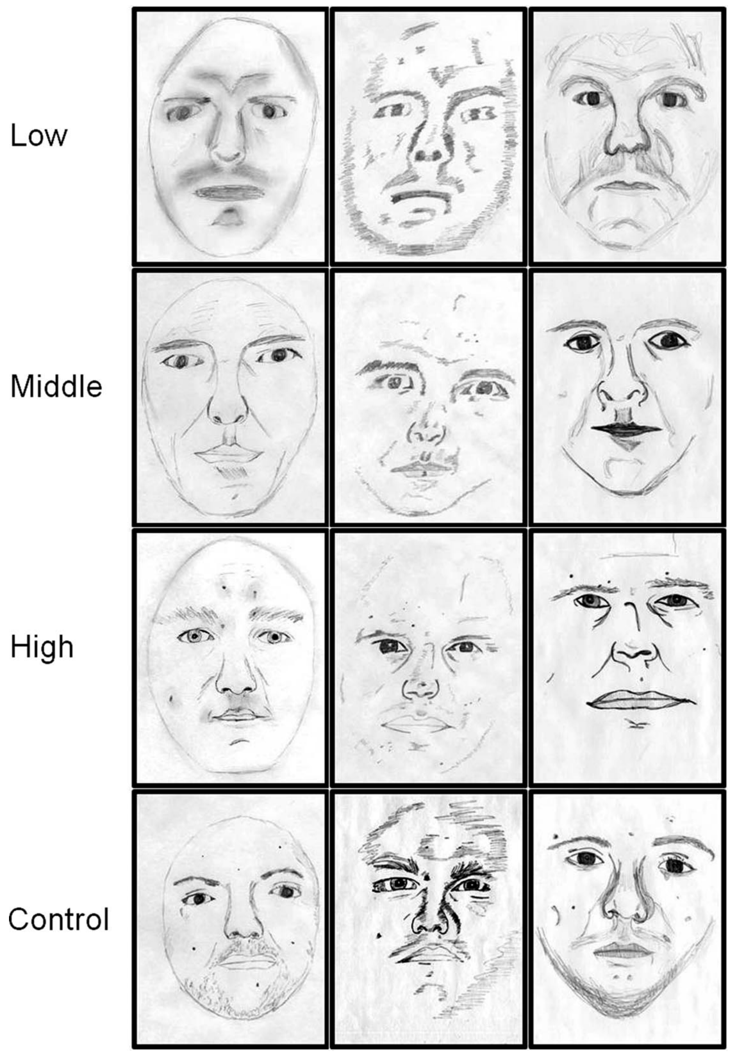

Figure 4. Example drawings obtained in the present study organized by the filter condition from which they were drawn.

the MSF condition produced lower accuracy than the other three conditions (e.g., LSFs, HSFs, and control). A simple explanation for our failure to support this hypothesis comes from differences in the task given to our participants versus those in earlier face recognition studies. Specifically, the current study asked artists to draw, not recognize, faces and they viewed the faces for 10 minutes each. Thus, it is plausible that the length of time required to draw, and the complexity of that task, changes which SFs are utilized for perception of a to-be-drawn stimulus. This suggests a dissociation between the information needed for face *recognition* and face *production.*

When considering the overall data pattern, an interesting interpretation presents itself. The data show that, in isolation, the LSFs and HSFs are more useful for drawing than the MSFs. Importantly, LSFs carry information about the global configuration of images (Goffaux et al., 2005) useful for rendering accurate spatial relationships and HSFs carry edge and detail information (Biederman, 1987; Biederman & Ju, 1988; Marr & Hildreth, 1980) useful for rendering individual facial features in detail. Because both LSFs and HSFs are present in the control condition, a possible explanation for the increased accuracy observed there emerges. When granted access to all SFs, artists are seemingly capable of selecting out the SF information that is useful for the drawing task in which they are engaged (e.g., defining edges of facial features or determining their spatial configuration). Because these tasks can be completed with HSFs and LSFs respectively, MSFs may supply redundant information.

If MSFs supply redundant information, how are artists capable of avoiding interference of the MSFs with the more useful LSFs and HSFs? We suggest that when given access to all SFs, artists are able to focus their efforts on using LSFs and HSFs, which appear to be more useful for drawing, while simultaneously ignoring the MSFs, which are useful for face recognition but redundant for drawing. Figure 5 represents this idea graphically, suggesting that the present study's data exhibits an inverse relationship to a hypothetical face recognition utility function—specifically, the

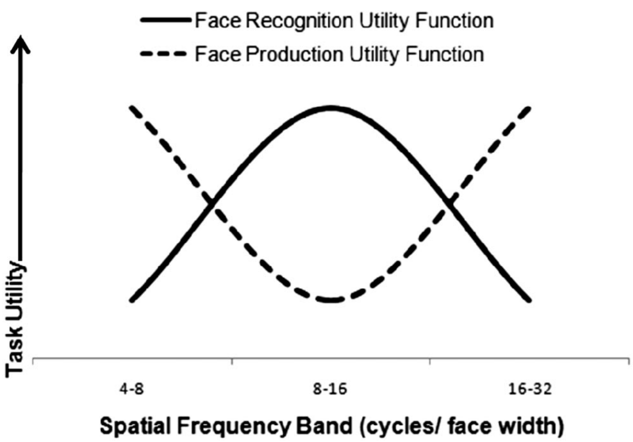

Figure 5. A hypothetical representation of the utility of low, middle, and high spatial frequencies for face recognition versus face drawing. The observed results indicate an inverse relationship between the two hypothetical spatial frequency utility functions such that the ubiquoutous MSFs that are more useful for face recognition are less useful for drawing relative to LSFs and HSFs.

SFs that are ubiquitous in faces (Keil, 2009), and that are most useful for face recognition (e.g., Costen, Parker, & Craw, 1996), are least useful for face 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). That research showed that during perception of naturalistic stimuli, people discount horizontal orientation information to which we are most sensitive (as indicated by the abundance of V1 neurons tuned to horizontal orientations, De Valois, Yund, & Hepler, 1982). They explained this finding in terms of the visual system discounting the ubiquitous and redundant visual information, thus making the information to which we are less sensitive more salient and more useful for the task.[5]

Consistent with this proposed discounting ability, Keil (2009) has shown that human faces contain a preponderance of MSFs (relative to LSFs and HSFs), just as natural scenes contain a preponderance of horizontal orientations. Thus, analogous to the arguments of Essock et al. (2003), in the current study it seems plausible that artists discounted the redundant MSFs in order to focus on the less available, but more useful, HSFs and LSFs that carry detail and configural information respectively.

The above argument claims that MSFs are not part of the useful information for drawing in the control condition, which suggests an additional hypothesis. If artists are provided with notch-pass filtered images with only the MSFs removed, drawing performance should be equal to, or better than, the present control condition. Additionally, if LSFs carry configural information and HSFs carry featural detail information, then if raters are asked to evaluate the accuracy of the drawings based on configural accuracy or featural detail accuracy, configural accuracy should be rated higher in the LSF condition and featural detail accuracy should be rated higher in the HSF condition. These are testable hypotheses for future research.

An additional avenue for future research would be to investigate which of the various face processing mechanisms (Tsao & Livingstone, 2008) are active while drawing portraits. For example, an alternative method to further test the hypotheses in the current study would be to use face adaptation methods, which make use of the fact that prolonged viewing of faces results in adaptation that affects facial perception (Carbon & Leder, 2005; MacLin & Webster, 2001; Moradi, Koch, & Shimojo, 2008). Thus, it would be interesting to know if face adaptation at different SF bands can affect the band of SFs that are used during drawing. According to the standard logic of spatial frequency adaptation studies (Blakemore & Campbell, 1969; Maffei, Fiorentini, & Bisti, 1973), including for faces (Eger, Schyns, Kleinschmidt, 2004), adaptation *reduces* sensitivity to the adapted stimulus. Thus, if HSFs and LSFs are most useful for face processing in drawing, then adapting to a notch-pass filtered version of a face containing only those frequencies should reduce sensitivity to them, and thus reduce drawing accuracy for a normal version of that face. Conversely, if MSFs are not useful for drawing, or perhaps even hinder it, then adapting to a band-pass filtered version of a face containing only those frequencies should reduce sensitivity to them, and thus would either have no effect on drawing accuracy for a normal version of that face, or perhaps even increase drawing accuracy for it.

Implications

The present data demonstrate that different SF bands have varying utility for drawing. Gaining such an understanding of drawing at both a perceptual and a cognitive level will allow us to develop and utilize drawing as a tool for assessment of perceptual, cognitive, motor, and decision making processes. Drawing has already proved useful for evaluating the perception of patients with deficits such as visual neglect or visual agnosia (Marshall & Halligan, 2004; Riddoch & Humphreys, 1987; Rubens & Benson, 1971; Shulman, 2000). Additional insight could be gained from such studies if we possessed a greater understanding of the low level perceptual processes that are active during drawing.

There is a need to develop working theories of art production grounded in the principles of low level perception. For example, Arnheim's (1974) *Art and Visual Perception,* showed the importance of Gestalt principles in perceiving artistic properties such as balance, shape, and form in creating and evaluating art (Cupchik, 2007; Verstegen, 2007;Wertheimer, 2007). Principles of spatial vision have more recently been applied to artistic evaluation (Bonnar, Gosselin & Schyns, 2002; Casco & Duzzon, 2008). However, the present study is the first of its kind in aiming to assess the utility of a range of spatial frequencies in the *production* of art. As such, it takes an important first step toward understanding the perceptual processes involved in drawing. Indeed, Cohen and Bennett (1997) have argued that perception of the to-be-drawn stimuli is perhaps the most significant cognitive contribution to peoples' ability to draw accurately. Interestingly, the present research has investigated this hypothesis and demonstrated the surprising result that what is most useful for face recognition is not synonymous with what is most useful for face reproduction.

[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).

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