

Context effects in visual perception and their explanations

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The context of a visual object is constituted by stimuli in its surround. Context effects are present when the perception of an object changes when its context changes, without any physical change in the object itself. Four classical examples of context effects of the perception of area, length, orientation, and lightness are presented in a common, structured format. A formal definition of context effects is provided. It is proposed that accounts of context effects can be classified into three explanatory strategies (psychophysical, physiological, and interpretational). A simple example of each strategy is presented (accounts based on contrast, lateral inhibition, and illumination interpretation), with special emphasis on explanations of the simultaneous lightness contrast effect. Features of these strategies are discussed, including their appealing aspects, but with a stress on their weak points.

Key words: context effects, visual illusions, explanatory strategies in perception

The term *visual field* generally refers to everything that one sees, in other words, our apprehension of the total instantaneous optical simulation. Among the many constituents of the visual field, there is usually one at which we direct our gaze and that captures our attention: this is a spatio-temporally limited configuration that I will call the *visual target*. The term *visual context* (with respect to a given target) may be used to refer to anything else in the visual field, other than the target. However, often this term refers only to a portion of the field located relatively near the target and surrounding it to some extent; the context may also temporally precede the target, but I will not deal with such phenomena here.

Since every target appears in some context, and the same target may be set in different contexts, the question arises whether (and if so, in what ways) the visual appearance of the target is affected by the presence of context. In this paper I will first present a few examples of such contextual effects, and will then discuss different general strategies for explaining them. The text is mainly expository and introductory in character, but occasionally provides somewhat more detailed conceptual analyses.

There is a fundamental psychophysical distinction between basic physical (objective) and perceptual (subjective) visual attributes of objects. The basic *physical attributes*

of visual objects, which can be objectively determined by measuring instruments and are independent of observers, are their size, shape, orientation, distance, spectral reflectance, and the like. The corresponding basic *perceptual attributes* involve the subjective appearance of physical attributes, ascertained on the basis of reactions of observers, and refer to perceived size, perceived shape, perceived spectral reflectance (or color) of the objects, etc. Attributes, both physical and perceptual, may have one or more *dimensions* along which their *values* may vary. For example, physical length is one-dimensional, whereas color, as perceived, is three-dimensional, and different objects have different values on the dimensions of hue, brightness, and saturation.

It is obvious that values of perceptual attributes of an object depend on values of corresponding physical attributes: the perceived size of an object depends on its physical size, its perceived shape depends on its physical shape, perceived color depends on surface spectral reflectance, etc. The manner of this dependence can be simple or complex. For example, the relation of physical length and perceived length is relatively simple, since as physical length increases, within certain bounds, perceived length increases more or less proportionally. On the other hand, as luminance (the intensity of light coming from an object) increases, its brightness (perceived luminance) does not increase linearly, but rather in a negatively accelerated manner, such as quantified by Fechner's or Stevens' laws. However, how the perceived properties of an object depend on its physical properties is not my topic here. Rather, the topic involves situations in which the physical attributes of an object, the target, remain constant, but its perceived attributes change, not because of

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any changes in the target itself, but due to changes in its context. To the uninitiated, it may seem surprising that such effects should exist at all. In our everyday perception, when we look at an object, intuitively it seems obvious that what we are aware of are just the properties of that object itself, and not of something else, beyond the object. However, contextual effects do exist, ranging from weak but noticeable to strong and perplexing, and present major challenges to our understanding of the working of perceptual mechanisms and cognitive processes in general.

Examples of contextual effects

In this section I will present four well-known examples of contextual effects, in a somewhat more methodical and structured manner than they are usually described. This common presentation format is useful for considerations of four relevant issues that arise when such effects are studied: they are *physical equality*, *perceptual equality*, *type of context*, and *veridicality*. The format involves four displays: in two of them the targets are physically equal and in two they are physically different; in two displays the targets are perceived as equal, and in two they are perceived as different; finally, in two displays the targets are presented in equal contexts and are perceived veridically, and in two they are presented in different contexts and are not perceived veridically, resulting in illusions.

Three aspects of contextual effects will be considered, labeled existence, direction, and magnitude. *Existence* refers to the question whether variation of context affects the appearance of the target or not; in all subsequent examples context effects do exist. *Direction* refers to the manner of change induced in the perception of the target by the presence of different contexts. *Magnitude* refers to the strength of the contextual effect, expressed numerically.

Contextual effects in the perception of size (area)

Panel (a) in Figure 1 contains two targets in the form of two physically identical disks. Their appearance is also equal, that is, they look the same, or at least very similar in size. Panel (b) contains the same two disks, but here they are surrounded by a number of other figures, the contextual disks. This figure, known as the Ebbinghaus illusion or Titchener circles, is a classical example of a contextual effect: although the targets are physically identical, whether they are perceived as identical or not depends on the presence and features of other objects in their surround. When they are in the same context, such as when no other objects are in vicinity, as in panel (a), the target disks look the same; however, when they are in a specific different context, that is, surrounded by objects of different sizes, as in panel (b), they look as if they had different areas (see e.g. Roberts et al., 2005; Rose & Bressan, 2002).

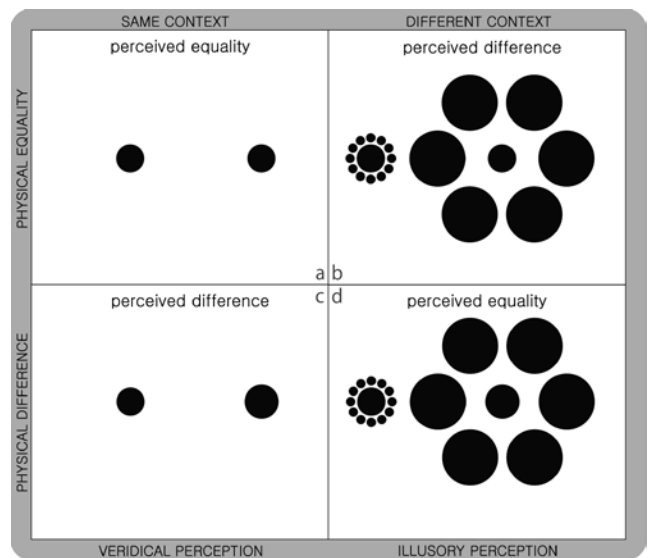


Figure 1. The effect of context in the perception of size. (a) Veridical perception: Disks with physically equal size, set in same context, are perceived as equal. (b) Illusory perception: Disks with physically equal size, set in different contexts, are perceived as different. (c) Veridical perception: Disks with physically different sizes, set in same context, are perceived as different. (d) Illusory perception: disks with physically different sizes, set in different contexts, are perceived as nearly the same.

The difference between panels (a) and (b) is not only phenomenological (referring to appearances), but also epistemological (referring to the relations of appearances and reality). In panel (a), appearance is in accord with reality, since the disks both are the same and look the same, so that the percept is *veridical*; in panel (b), appearance and reality are in discord, since the disks are the same but look different, so that the percept is *illusory*.

There is more to be said about the appearance of the two target disks, in addition to just stating that there *exists* a context effect, meaning that they look different. Namely, the context effect has a particular *direction*: the target disk surrounded by larger contextual disks looks *smaller* (rather than, say, unchanged or larger) than the one surrounded by smaller contextual disks. Any theory of this effect would have to explain why the effect of context has manifested itself in this particular direction.

Furthermore, the difference in appearance of the targets also has a certain *magnitude*. That is, it makes sense to ask *how much* smaller one target disk looks than the other. A complete theory should be able to predict not only the direction but also the magnitude of the perceptual effect. However, the question concerning magnitude is not readily answered. By casually inspecting the display, all that can be said seems to be that one disk looks somewhat, but not much smaller than the other.

The magnitude of the difference in appearance can be ascertained more precisely, but to do that one needs to go beyond casual observations and perform psychophysical experiments. Such experiments can take various forms, which have different advantages and disadvantages. One popular procedure is to adjust the size of one target until it *looks the same* as the other target. This can be done a number of times, by several observers, using some technical device, such as a computer. If such a procedure is applied to the smaller looking target disk in panel (b), the adjustment will consist in its enlargement, in order for it to look equal in size to the other target disk. Suppose that the average enlarged disk is presented in panel (d) of Figure 1. In this display the target disks are different but they look equal, or at least more similar in size than the target disks in panel (b), which are actually physically equal. However, when the contextual disks are removed from this display, such as in panel (c), the two target disks do look different, in accord with their physical difference. Thus context can not only make physically equal objects appear different but can also make different objects look equal, which is another example of non-veridical perception.

Whereas a presentation such as in panel (b) is useful to conveniently *demonstrate* the influence of context, because it is easy to show that the targets are physically the same although they look different, when one wants to *measure* the illusory effect, it is more convenient to use an experimental procedure, such as resulting in panel (d). Here the illusion is measured by comparing the physical sizes of the target disks. In particular, the radius of the target disk surrounded by larger contextual disks is 20% larger than the radius of the other target disk; this number is a quantitative measure of the magnitude of the illusion. Expressing the illusion measure in relative values, such as in percentages, is more appropriate here than expressing it in absolute values, such as in millimeters, because absolute measures depend on the size of the printed page and on the computer screen zoom level.

Note that with this method the magnitude of the context effect is measured in a setup in which it is manifested in illusory perceptual equality despite physical difference. One could also attempt to assess the context effect in the converse situation, when it is manifested in perceptual difference in spite of physical equality, as in panel (b). The problem is that in that case one would have to ask observers to quantitatively judge the difference in appearance between the two targets, which is a difficult and unreliable task ('how much larger does one disk *look* than the other'). The task is easier and the data are more reliable when observers are asked to perform a simpler perceptual judgment, such as whether two targets appear equal, and then the experimenter performs quantitative measurements on the corresponding physical attributes of targets ('how much larger *is* one disk than the other'), since relative magnitude is much more easily ascertained for physical attributes than for perceptual attributes.

The displays in Figure 1 provide illustrations of the main form of the Ebbinghaus illusion. Various parameters of this basic figure can be manipulated, such as size and number of the target and contextual elements, as well as their shapes, colors and mutual distances. Measuring how the strength of the illusion depends on these features can help us understand the cause of this phenomenon. However, it is not my purpose in this paper to provide detailed information of this type (see e.g. Roberts et al., 2005, and Rose & Bressan, 2002).

In the following I will present three more classical examples of context effects. They will be displayed in the same format as Figure 1, in order to stress the great formal similarities between them as contextual effects, although they deal with different attributes and types of contexts. The accompanying text will be shorter, because the main general conceptual issues are common to all effects and were already discussed above.

Contextual effects in the perception of size (length)

In the example in Figure 1, the notion of size referred to areas of two-dimensional figures. Context effects exist also for the perception of length of linear extents. An example is the Müller-Lyer illusion, one of the best known phenomena in visual perception. Figure 2, using the same

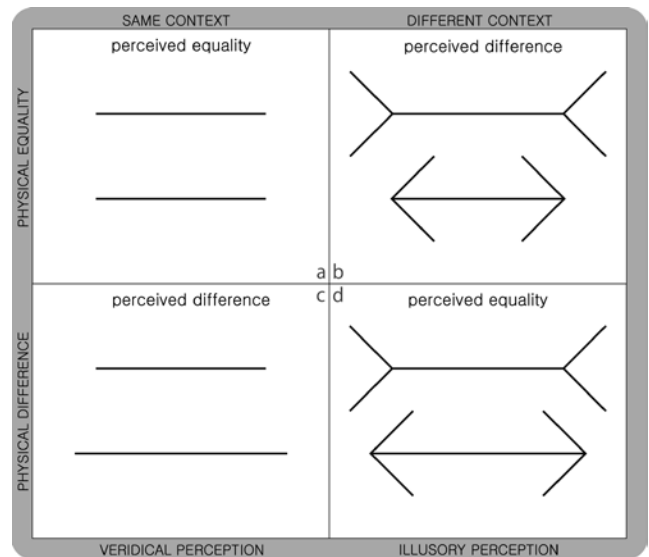


Figure 2. The effect of context in the perception of length. (a) Veridical perception: lines with physically equal lengths, set in same context, are perceived as equal. (b) Illusory perception: lines with physically equal lengths, set in different contexts, are perceived as different. (c) Veridical perception: lines with physically different lengths, set in same context, are perceived as different. (d) Illusory perception: lines with physically different lengths, set in different contexts, are perceived as nearly the same.

format as Figure 1, shows how lines of same length, which when presented on featureless background look the same, as in panel (a), appear to have different lengths if additional short lines forming chevrons (V-shaped patterns) are added at their endpoints as context, as in panel (b) (see e.g. Greene & Nelson, 1997; Post et al., 1998; Howe & Purves, 2005).

Similarly as for the Ebbinghaus illusion, one can try to make the lines appear equal by making them physically different. The result of such an attempt is presented in panel (d). When the chevrons are removed, as in panel (c), the two lines clearly look different, which indeed they are.

The *direction* of this effect is such that inward pointing chevrons make lines appear shorter than outward pointing chevrons. The *magnitude* of the effect can be established by determining the ratio of physical lengths of perceptually equalized lines. In panel (d), the physically longer line is 25% longer than the physically shorter line to which it looks similar in length.

Contextual effects in the perception of orientation

Figure 3 presents the Zöllner illusion, which demonstrates the effect of context in the perception of orientation. The five diagonal lines in panel (a) are mutually parallel. In panel (b), additional short lines are present, such that the

diagonal lines 1, 3, and 5 are crossed by short lines of one orientation, whereas lines 2 and 4 are crossed by short lines of another orientation. In such a context, the diagonal lines do not look parallel any more (see e.g. Kitaoka & Ishihara, 2000; Morgan & Casco, 2000).

In panel (d), the diagonal lines 2 and 4 are rotated slightly counter-clockwise, and as a consequence all lines now appear parallel, or at least more aligned with each other than the lines in panel (b). Without the crossing short lines, as in panel (c), it is easily seen that the long lines are not mutually parallel.

The *direction* of this effect can be ascertained as follows. When two lines cross they form four angles, and the opposite pairs of angles are equal; I will refer to the smaller angle as 'the angle' between the crossing lines. The geometry of the display in panel (b) is such that the angle from the diagonal lines to the short crossing lines is oriented counter-clockwise for lines 1, 3, and 5, and clockwise for lines 2 and 4. The perception of the display is such that the diagonal lines do not look parallel, but as if rotated *away* from the short lines, that is, lines 1, 3, and 5 clockwise and lines 2 and 4 counter-clockwise. The *magnitude* of the effect can be measured by the angle subtended by the directions of lines 1, 3, 5 and lines 2, 4 in panel (c) or (d), and it amounts to 4 degrees. Expressing this value in terms of percentages, as was done for the previous two effects, would not be appropriate, because angles are cyclical measures; it is also not necessary, since angles do not depend on the size of the display.

Contextual effects in the perception of lightness

Figure 4 presents the simultaneous lightness contrast effect, a phenomenon that goes back at least to Goethe early in the 19th century, and has been studied in detail since (see e.g. Kingdom, 1997; Gilchrist, 2006). The two target squares in panel (a) are positioned on the same background and have equal luminance, that is, they reflect physically the same amount of light into the observers' eyes. Phenomenologically, they also *appear* to have much the same color, or gray level. However, when they are put on different backgrounds, one dark and the other light, such as in panel (b), their perceived gray levels are no longer the same.

In panel (d) an attempt was made to change the luminance of the target on the light background such that it appears the same as the target on the dark background. An ideally satisfactory perceptual match is hard to achieve for displays of this type, but at least it can be said that the two targets here look more similar in lightness than the two physically equal targets in panel (b). However, when they are put in the same context, that is, on the same background, as in panel (c), they appear different in lightness, in accord with the fact that their luminances are different.

The *direction* of the effect is such that the target on the light background looks darker than the same target on the

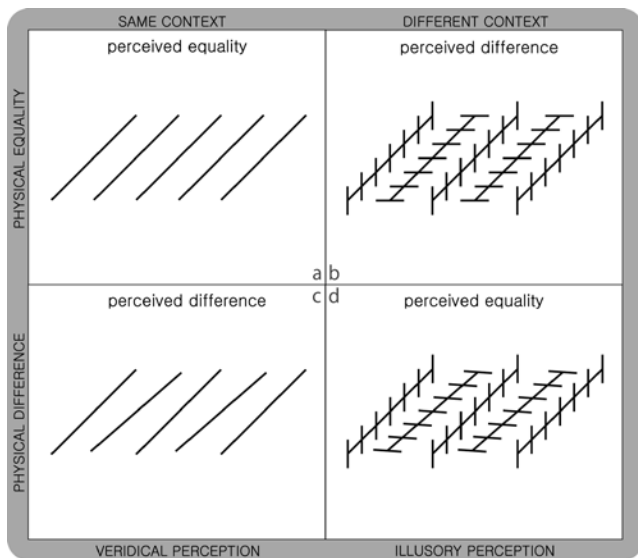


Figure 3. The effect of context in the perception of orientation. (a) Veridical perception: lines that are mutually parallel, set in same context, are perceived as mutually parallel. (b) Illusory perception: lines that are mutually parallel, set in different contexts, are not perceived as mutually parallel. (c) Veridical perception: lines that are not mutually parallel, set in same context, are perceived as not mutually parallel. (d) Illusory perception: lines that are not mutually parallel, set in different contexts, are perceived as nearly mutually parallel.

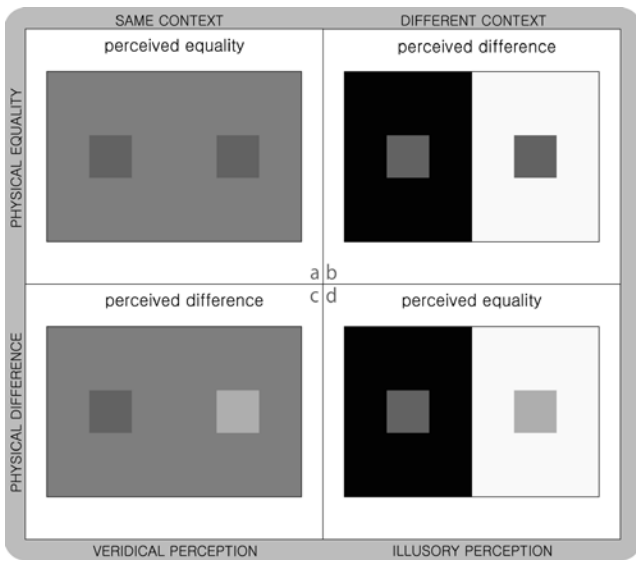


Figure 4. The effect of context in the perception of lightness. (a) Veridical perception: patches of equal luminance, set in same context, are perceived as equally light. (b) Illusory perception: patches of equal luminance, set in different contexts, are perceived as differently light. (c) Veridical perception: patches of different luminance, set in same context, are perceived as differently light. (d) Illusory perception: patches of different luminance, set in different contexts, are perceived as nearly equally light.

dark background. The determination of the *magnitude* of the effect is more involved here than in the previous examples, because it would necessitate the use of specialized instrumentation to measure the amount of light reflected by different surfaces. According to the graphical program that was used to construct these displays (in which black is denoted as 0% and white as 100%), in panel (d) the target on the dark background has a gray level of 50%, whereas the target on the light background has a gray level of 75%. However, these values, although monotonically related to luminances, are not linearly proportional to them, and the perception of the targets is likely to be affected differently when they are presented on different computer screens or printed on different printers.

Formal definition of context effects

There are many more examples of effects of context, but these four will suffice for the purpose of this paper. Based on their format, here is one way to define the effects of context in visual perception more formally and generally. Suppose that there are two targets, T_1 and T_2 , which share the same physical, objective target attribute O_T , such that $O_{T1} = O_{T2}$; examples are two disks of same size (Figure 1), two lines of same length (Figure 2), two (or more) lines of the same orientation (Figure 3), and two gray patches of equal

luminance (Figure 4). Suppose that the targets are embedded in two corresponding contexts, C_1 and C_2 , which differ in the value of an objective context attribute O_C , that is, $O_{C1} \neq O_{C2}$; examples are contextual disks of two different sizes, chevrons of two different angles, crossing lines of two different orientations, and backgrounds of two different luminances. By definition, a contextual effect exists if the objectively equal targets, set in different contexts, differ in the value of a perceptual, subjective target attribute S_T , that is, if $S_{T1} \neq S_{T2}$; examples are two equal disks perceived to have different sizes, two equal lines perceived to have different lengths, two (or more) parallel lines perceived to have different orientations, and two equal gray patches perceived to have different gray values. Fully formally, a context effect exists if the following set of conditions holds: $\{O_{T1} = O_{T2}, O_{C1} \neq O_{C2}, S_{T1} \neq S_{T2}\}$

The above definition is based on context effects as exemplified in the (b) panels of Figures 1- 4. A definition based on the (d) panels is also possible: a context effect exists for the following set of conditions $\{O_{T1} \neq O_{T2}, O_{C1} \neq O_{C2}, S_{T1} = S_{T2}\}$. These definitions deal only with the *existence* of context effects, and involve statements of equality and difference of visual attributes. The specification of the *direction* of context effects, which usually involves statements concerning ordinal comparisons of visual attributes, will be addressed later on.

Explanatory strategies for contextual effects

What is the explanation of the effects of context in visual perception? Why do the perceived attributes of targets not depend solely on their physical attributes, but are also affected by other parts of the visual field? There is no single answer to such a broad question. Many explanations have been offered for various context effects in the literature, but there is still no consensus for quite a few effects. In fact, there seems to be no general consensus as to what constitutes an acceptable explanation, since different researchers adopt different frameworks within which explanations are formulated. Here I will outline three such general frameworks or *explanatory strategies*. This classification is tentative and not exhaustive, and the strategies are not necessarily mutually incompatible but are rather, ideally, complementary. However, they do reflect interestingly differing styles of thought, or different scientific philosophies that researchers tend to adopt as favorite ways to approach the problems of context, or indeed perception in general.

I will label the three approaches as the psychophysical, the physiological and the interpretational explanatory strategy. In the *psychophysical strategy* the explanation is formulated in terms of features of the stimulus, and the stress is put on how the physical input to the visual system relates to the perceptual output. The *physiological strategy* prefers accounts couched in terms of neuronal reactions and neural interactions, that is, the stress is on the structure of the ef-

fect that the stimulus exerts on the visual nervous system. Finally, the *interpretational strategy* seeks to understand these phenomena in terms of somewhat higher-level, intelligence-like processes, such that the stress is on various mental or computational strategies that observers apply to the deliverances of the senses in order to interpret them, and in this way to correctly reconstruct some aspect of their environment.

Within each of these strategies there are many different concrete explanatory accounts. Here I will consider only one rather simple proposal per strategy, and concentrate mainly on accounts of the simultaneous lightness contrast effect. The three proposals have quite different ‘explanatory flavors’, but all may initially seem reasonably plausible. When discussing them, I will first briefly point out their positive aspects, but will then concentrate on outlining various limitations and difficulties of these proposals, and, in some instances, how they may be overcome.

An example of the psychophysical strategy: the contrast account

In this approach the appearance of the target is explained in relation to the features of the stimulus. There are many ways in which such accounts may be formulated. The type of explanation that I will devote my attention to here is an account in which context effects are explained by invoking the notion of the *contrast* of the target and the context. For example, in this approach the Ebbinghaus illusion is explained by noting that one target disk is surrounded by larger disks, and in contrast to them appears smaller, whereas the other target disk is surrounded by smaller disks, and in contrast to them appears larger. Similarly, the explanation of the simultaneous lightness contrast effect, indicated in its very title, is that the two gray patches look different because they contrast with their respective backgrounds, which is why the one on dark background appears lighter, and the one on light background appears darker.

What can be said about this type of account? On the one hand, such a proposal has several appealing features. For example, it is general, since it appears to be applicable for qualitatively different attributes, such as size and lightness. Furthermore, such an account is predictive and falsifiable, in that for a given target and context one can, in principle at least, deduce which consequence the physical relation of context and target should have for the appearance of the target according to the contrast account, and then test whether that prediction comes true. In addition, a contrast account seems to have face validity, since it appears intuitively plausible that physical features of objects may be perceptually evaluated in comparison with and in relation to analogous features of nearby, related objects.

On the other hand, there are quite a number of aspects in which the contrast explanation is limited or problematic.

Before addressing them, I will elaborate one way in which this notion can be made more formal, based on the above definition of context effects. Recall that in situations such as presented in the (b) panels of the figures, the objective attributes are equal for the targets ($O_{T_1} = O_{T_2}$), but are different for the contexts ($O_{C_1} \neq O_{C_2}$). To express the *direction* of this difference, this nominal statement must be expressed ordinally. If the objective attributes are one-dimensional (such as size or luminance), one of these values must necessarily be smaller and the other larger, and I will arbitrarily assume that this value is smaller for the first context, that is, that $O_{C_1} < O_{C_2}$ holds; for example, in the Ebbinghaus illusion, this means that the size of one set of contextual disks (C_1) is smaller than the size of the other set of contextual disks (C_2), and in the simultaneous lightness contrast display, this means that one background (C_1) has lower luminance than the other background (C_2). I will define *contrast* to be present if the value of the relevant perceptual, subjective attribute S_{T_1} of the target T_1 is *larger* than the corresponding value of the attribute S_{T_2} of target T_2 , that is, $S_{T_1} > S_{T_2}$ holds. Formally, contrast is defined by the following set of conditions: $\{O_{T_1} = O_{T_2}, O_{C_1} < O_{C_2}, S_{T_1} > S_{T_2}\}$. For the Ebbinghaus illusion, this means that the target disk (T_1) surrounded by smaller contextual disks (C_1) looks *larger* than the physically equal target disk (T_2) surrounded by larger contextual disks (C_2); for the simultaneous lightness contrast displays, this corresponds to the situation in which the target (T_1) on the low luminance background (C_1) looks *lighter* than the equi-luminant target (T_2) on the high luminance background (C_2).

Another definition of contrast can be based on the (d) panels in the figures, expressed in the following set of conditions: $\{O_{T_1} > O_{T_2}, O_{C_1} < O_{C_2}, S_{T_1} = S_{T_2}\}$. In this case, as it was shown in the examples, the *magnitude* of the effect can be determined in different ways, for example by computing the ratio O_{T_1}/O_{T_2} and expressing it as a percentage, or by computing the difference $O_{T_1} - O_{T_2}$.

Let me return to the first definition of contrast, given by the conditions $\{O_{T_1} = O_{T_2}, O_{C_1} < O_{C_2}, S_{T_1} > S_{T_2}\}$. Suppose now that again $O_{T_1} = O_{T_2}$ and $O_{C_1} < O_{C_2}$ hold, but that $S_{T_1} = S_{T_2}$. This set of conditions refers to cases of absence of context effects, because although the contexts are different, the perceptual attributes of the targets are equal. More interestingly, note there is a third possibility, and that is that again $O_{T_1} = O_{T_2}$ and $O_{C_1} < O_{C_2}$ hold, but that $S_{T_1} < S_{T_2}$; such a possibility can indeed be perceptually realized and is called *assimilation*. To summarize, context effects for one-dimensional attributes involve two targets with physically equal attributes ($O_{T_1} = O_{T_2}$), and two contexts such that for one context the relevant physical attribute is smaller than for the other ($O_{C_1} < O_{C_2}$). One type of context effects is contrast, in which the direction of the perceptual difference of the targets ($S_{T_1} > S_{T_2}$), is *opposite* to the direction of the physical difference of their contexts, and the other type is assimilation, in which these two directions are *equal* ($S_{T_1} < S_{T_2}$). In

contrast effects the perceived attributes of the targets can be said to shift *away* from their contexts and become more different from them, whereas in assimilation effects the perceived attributes shift *towards* their contexts and become more similar to them (examples corresponding lightness phenomena will be discussed below).

In standard demonstrations of contrast, the value of the physical attribute of the target (O_T) is often *intermediate* between the corresponding values of the context, that is, $O_{C_1} < O_T < O_{C_2}$. Thus in the Ebbinghaus illusion the target disks are smaller than the surrounding disks in one context and larger than the surrounding disks in the other context; similarly, in the simultaneous lightness contrast effect, the luminance of the target patches is usually in between the luminances of the two backgrounds, that is, it is an increment with respect to C_1 , but a decrement with respect to C_2 . It is an empirical question, which I will not pursue here, whether and to what extent context effects exist when the value for the target is not intermediate but rather higher or lower than the values for both contexts, that is, when $O_T < O_{C_1} < O_{C_2}$ or $O_{C_1} < O_{C_2} < O_T$.

An interesting issue in the study of context effects is the existence of *neutral* contexts, symbolized here as C_N . These are contexts for which it can be shown or reasonably assumed that they do not affect the appearance of targets, that is, that S_{TN} does not depend on O_{CN} , and thus C_N can serve as an appropriate baseline or control condition. If such a context exists then, in addition to comparing the effects of C_1 and C_2 with each other (yielding the contrast relation $S_{T1} > S_{T2}$), one can also compare separately the appearance of the two targets in contexts C_1 and C_N (yielding the relation of S_{T1} and S_{TN}), and in contexts C_2 and C_N (yielding the relation of S_{T2} and S_{TN}). For example, in the Ebbinghaus illusion the neutral context C_N for the targets might be constituted by the condition in which the target is presented isolated, with no contextual disks surrounding it (similar as depicted in Figures 1a and 1c for both targets). Comparisons of the appearance of the target surrounded by small contextual disks (C_1) with the target alone (C_N), and of the target surrounded by large contextual disks (C_2) with the target alone (C_N), can yield several possible outcomes that may clarify the source of the contrast effect. For example, the perceived size of the target in the neutral context (S_{TN}) might be smaller than when it is surrounded by smaller disks (which can be labeled as the ‘inflating effect of small disks’, $S_{TN} < S_{T1}$), and also larger than when it is surrounded by larger disks (‘shrinking effect of large disks’, $S_{TN} > S_{T2}$), yielding the overall relation $S_{T1} > S_{TN} > S_{T2}$. However, it might also be the case that only the inflating effect exists, $S_{T1} > S_{TN} = S_{T2}$, or that only the shrinking effect exists, $S_{T1} = S_{TN} > S_{T2}$, or even that both non-neutral contexts induce inflation, but that the inflation effect is stronger for smaller contextual disks, $S_{T1} > S_{T2} > S_{TN}$, or that they both induce shrinking, but that the shrinking effect is stronger for larger contextual disks, $S_{TN} > S_{T1} > S_{T2}$. Similar considerations apply for other illusions.

One problem here is to decide which control condition is legitimate. For example, in the Ebbinghaus illusion, in addition to the empty context condition, another candidate for a control condition is one in which the context is not empty and the target is surrounded by contextual disks, but they have the same size as the target disk. In the Müller-Lyer illusion, control conditions might be constituted by lines without any chevrons, or by ‘chevrons’ constituted by perpendicular lines. In the Zöllner illusion, control conditions might be constituted by diagonal lines without any crossing lines, or by crossing lines oriented at right angles to diagonal lines. Finally, in the simultaneous lightness contrast display (in which it would be of interest to study whether the different appearance of the targets in Figure 4b is due to a ‘darkening effect’ of the high luminance background, a ‘lightening effect’ of the low luminance background, or both, or even whether both contexts work in the same direction but with different strengths), the problem is that it is not clear how to construct a fully adequate neutral context. In this case, in contrast to the previous three, it is not possible to construct an ‘empty context’, because the luminance of the surround is the relevant contextual attribute, and the target always has to have a surround of *some* luminance and color; even zero-luminance backgrounds would not correspond to colorless but to black contexts, which are not necessarily neutral.

Let me now return to the general assessment of the contrast account. One of its shortcomings is that it provides only a qualitative prediction of the direction of change of appearance of the target, but does not, in its basic form, predict the magnitude of that change. It appears plausible that larger differences between the target and the context should be associated with larger effects on the target, but this is an empirical issue, not dealt with in the contrast account, at least as defined above.

A very important limitation of the contrast account is that, as defined, it only strictly applies to single-valued contexts. For example, in the simultaneous lightness contrast effect, it is presupposed that in each context the background has a single, uniform luminance. In the Ebbinghaus illusion, although such an approach does not prescribe the number of surrounding context objects (in fact, this number is an important independent variable in the study of this illusion), it does presuppose that they are all of the same size, either larger or smaller than the target. Thus an important challenge for the contrast account is to handle situations with multiple-valued contexts. In the Ebbinghaus illusion, this involves cases in which the target object is surrounded by objects of different sizes, a situation that apparently has not been studied much. In the study of lightness, these are cases involving complex backgrounds, such that the target is surrounded by two or more surfaces of different luminances, some of which may be higher and others lower than the target luminance; furthermore, such surfaces may have different areas and may be located at different distances from the target, some adjacent to it and others not in immediate contact with it.

One reasonable way to generalize the contrast account so that it becomes applicable to multi-valued contexts is to propose that the appearance of the target is the resultant of some kind of *average* contrast effect of all constituents of the context, weighted, say, by their area and distance from the target. However, there are phenomena in lightness perception that are difficult to explain even within a generalized contrast approach, and thus strongly challenge it. The first such effect was discovered by Max Wertheimer and described by Benary (1924). More recently, a more salient example was studied by White (1979) and many other authors.

Figures 5a and 5b present a related example of an effect problematic for the contrast account (after Todorović, 1997). The targets are the cross-shaped gray patches at the center of these figures, denoted as A and B. The targets have the same luminance, but cross A looks somewhat darker than cross B. The two figures share the same geometry, but cross A is positioned on a white background and is surrounded by a quartet of black squares, whereas cross B is positioned on a black background and is surrounded by a quartet of white squares. Note that the portion of the border that the crosses share with the adjoining squares is two times longer than the portion of the border they share with their backgrounds. This means that a generalized contrast account, in which the effect of the different parts of the context is proportional to the length of the border shared with the target, should predict that the lightness of the targets is to a larger extent determined with reference to the luminance of the squares quartets than with respect to the luminance of the backgrounds. Thus according to this prediction cross A, adjoined by twice as much black than white, should look lighter than cross B, adjoined by twice as much white than black; The problem is that in fact A looks darker than B. This lightness effect is not very strong, but it is intriguing, because, simi-

lar to the Wertheimer-Benary effect and White's effect, to which it is structurally related, it has the 'wrong' direction, from the standpoint of the contrast account of lightness (see also the discussions of this effect in Palmer, 1999; Blakeslee & McCourt, 1999; Howe, 2001; Todorović, 2001; Güçlü & Farrel, 2005; Ghosh, 2006).

How can the challenge to the contrast account provided by these and related phenomena be met? One possibility is to give up on the usefulness of contrast as an explanatory notion in lightness perception, and search for some other principles. Another possibility is to keep this notion but to restrict its domain of application. One idea is to assume that the context within which the contrast account applies is not equivalent to the whole visual field other than the target, but only to a particular portion of the target surround. In particular, the appearance of targets in Figures 5a and 5b could be accommodated within the contrast account if the effect of contrast would not apply for the squares but would be restricted to the background; in this case, the contrast account would correctly predict that the target on the white background looks darker than the target on the black background. The problem is how to properly motivate this restriction.

One possibility is to propose that the target may contrast only with the part of the visual field with which it *groups*, or to which it is perceived to *belong* (see Gilchrist, 2006; Agostini & Galmonte, 2002). Note that in Figure 5 the crosses may be perceived to belong to the background and not to the square quartets. However, an issue with applying the idea of belongingness is that it is a phenomenological and not a physical concept, that is, it refers to subjective features of the percept (describing how some aspect of the scene is perceived), and not to objective features of the stimulus (describing some aspect of the geometry or the photometry of the scene). Thus to formulate a proper psychophysical ac-

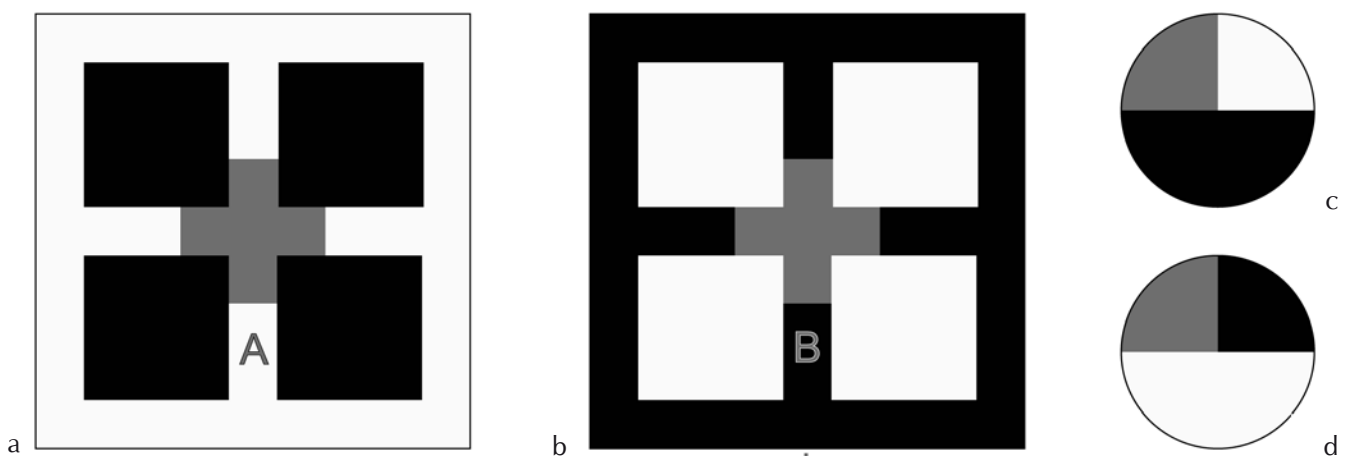


Figure 5. (a, b) Crosses and squares illusion. Crosses A and B have the same luminance, but cross A looks darker than cross B, although according to a generalized contrast account it should look lighter. (c) T-junction type present in (a). (d) T-junction type present in (b).

count, one would need to specify, in stimulus terms, under what conditions portions of the visual field will be perceived to belong to each other. A set of such conditions is described by the well-known Gestalt principles of grouping (see e.g. Todorović, 2008). However, none of the classical principles seems to apply directly for the regions of Figure 5a and 5b.

Another possible account is based on the so-called *T-junctions* present in this stimulus, examples of which are indicated in Figures 5c and 5d. These are ubiquitous image features, present whenever an object partially occludes another object. They are constituted when adjoining portions of three regions are delineated by two lines, one labeled as the 'stem' and the other as the 'top', in the form of letter T (which may be rotated by any angle). Figure 5a contains, at eight locations, T-junctions of the Figure 5c type, in various orientations; Figure 5b contains, at corresponding locations, T-junctions of the Figure 5d type. Using this notion, one can formulate the rule that the target will contrast with the portion of the surround positioned along the *stem* of T-junctions. Such a rule successfully predicts the lightnesses of the targets in Figures 5a and 5b (for details, see Todorović, 1997). Thus T-junctions may serve as inducers of belongingness (see Gilchrist, 2006). However, a T-junction account is limited to displays which contain T-junctions, and even in such displays other factors may also be at work (see Howe, 2001; Todorović, 2001).

Still another possibility is based on the observation that the targets in Figures 5a and 5b appear to reside on a different depth plane than the square quartets: the squares appear to be located in front, whereas the crosses (which may also look like gray squares partially occluded by the square quartets) appear as behind, located in the background. Therefore, one possible way to account for lightness effects in this figure is to propose that contrast effects are limited to objects that reside in the same depth plane (see Palmer, 1999; Howe, 2001). However, a problem for this view, pointed out

in more detail by Todorović (1997, 2001), is that White's effect is structurally rather similar to Figure 5 and involves the same intriguing lightness phenomenon; this makes it plausible that the two effects should have the same explanation. However, White's figure looks like a mosaic and does not involve perceived depth plane differences.

A serious challenge to the contrast account is posed by lightness phenomena that appear very hard to accommodate within it. Recall that the contrast account predicts that the lightness of the target should shift *away* from its context (such as gray appearing darker when surrounded by white and lighter when surrounded by black). However, in some figures, which exhibit the phenomenon of *lightness assimilation*, target lightness shifts *toward* the context (such as gray appearing lighter when surrounded by white and darker when surrounded by black). In fact, White's effect and related phenomena can be treated as examples of assimilation (see Anstis, 2005).

A classical example of lightness assimilation is presented in Figure 6 (after Helson & Rohles, 1959). Figures 6a and 6b contain gray stripes of equal luminance, but 6a also contains black stripes whereas 6b also contains white stripes. Note that according to the contrast account, the gray in 6a should look lighter than the gray in 6b; however, to most subjects it is the gray in 6a that looks darker (though this effect may be less stable than simultaneous lightness contrast, and some viewers, including the present author, have difficulties to observe it under some conditions). This outcome is described by saying that in this case the percept of gray *assimilates* to the context (rather than contrasts with it), so that it appears darker next to black and lighter next to white, which is the opposite direction to contrast. The problem for the contrast account is that in cases such as Figure 6 and similar effects, unlike with the Wertheimer-Benary and related phenomena, the option to explain them through restricting the effectiveness of contrast to a portion of total context does not appear to be available.

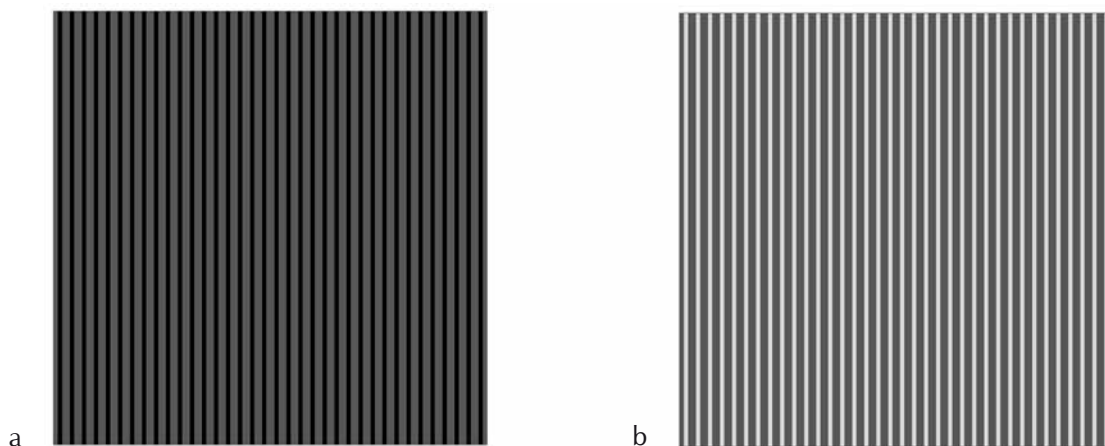


Figure 6. Lightness assimilation. Gray stripes in (a) and (b) have the same luminance, but to many observers look darker in (a) than in (b).

Finally, there is a problem concerning the status of the contrast account, in the following sense. When contrast is invoked, should that be regarded as a description, a prediction, or an explanation? It does seem appropriate and helpful to use it to *describe* perceptual effects, providing shorthand reports of directions of context-induced phenomena in certain displays. A contrast account can also be useful for the purpose of *predicting* the direction of effects in novel figures, and as such can serve to formulate hypotheses that can be verified or falsified (and are indeed falsified in a number of examples discussed above). But it seems less appropriate to use contrast as an *explanation*, such as claiming, say, that a surface is perceived to have a certain lightness level *because* of contrast. The problem is that an explanatory account seems to require a mechanism, and the contrast account, as defined above, does not postulate one. These same remarks apply to assimilation, or any other purely psychophysically defined account. Such accounts are indispensable for providing lawful input-output relations, describing and predicting *that* certain stimuli lead to certain percepts, but there still remains the question *why* such regularities should obtain. In other words, rather than providing explanations, one may view psychophysical accounts as providing regularities that need to be explained themselves. One way to address this type of question is to look for neural foundations of psychophysical relations, as exemplified in the physiological strategy.

An example of the physiological strategy: the lateral inhibition account

When light reflected from a stimulus strikes the cornea of the eye, it continues to propagate through several ocular tissues until it hits the retina and is absorbed, at which point the optical phase of the visual process ends and the neural phase begins. From the retina the main visual route proceeds to a sub-cortical nucleus in the thalamus, and then to area V1 in the occipital cortex, from where the signal is distributed to a number of other cortical visual areas, which are generally interconnected with each other in both directions. Each of these neural structures consists of several neural layers, each layer containing several types of neurons, totaling hundreds of millions of cells. This broadly distributed neural action eventually leads to the conscious awareness of the percept, in a manner which is not yet fully understood. Nevertheless, because of the obvious relevance of neural processes for perception, many accounts of perceptual phenomena have been couched in neural terms.

An example of the use of the physiological strategy is the proposal that many perceptual effects can be explained by the process of *lateral inhibition* (Coren, 1970). This is the phenomenon that neurons adjacent to each other in a neural layer may send mutual inhibitory signals, in proportion to their own activation. For example, suppose that there are two neighboring cells, X and Y, such that X receives

stronger activation from the stimulus than Y. Since, in addition to the bottom-up stimulus-based activation, there is also mutual lateral inhibition between them, the final activation levels of both cells will be lower than if they were isolated from each other. Furthermore, since the initial activation of cell X is higher, its inhibitory effect on cell Y will be more intense than the corresponding inhibitory effect of cell Y on cell X.

An account of the simultaneous lightness contrast effect popular in textbooks (though occasionally with caveats that this probably is not the full explanation) is based on the notion of lateral inhibition. Consider the two gray target patches in the simultaneous lightness contrast stimulus, presented again in Figure 7a. Because the two patches have the same luminance, the neurons stimulated by them will be initially activated to the same level, but will then be inhibited by adjacent cells which are stimulated by the surrounds of the patches. Cells stimulated by the white surround will be highly activated and therefore will send strong lateral inhibitory signals to their neural neighbors, whereas cells stimulated by the black surround will be weakly activated, so that their inhibitory signals will be weak as well. In consequence, the cells stimulated by target patch B, located on the white surround and thus exposed to strong lateral inhibition, will in the end have a *lower* activation level than the cells stimulated by patch A, on the black surround. This is why patch B looks darker than patch A. Note that this explanation is related to a contrast account in which *both* surrounds involve darkening of the target, but the darkening effect is stronger for the white surround.

There are several appealing aspects of this explanation. It provides a concrete example of the way perception can be grounded in neural activity, showing how an intriguing visual effect can result as a byproduct of a general physiological principle. Also, it proposes to provide a genuine causal account, explaining *why* it is that one patch looks darker than the other. On the other hand, this idea has several limitations and problematic aspects, both as an account of simultaneous lightness contrast and as a general explanation of lightness effects (see Gilchrist, 2006). I will point out a few issues here.

Lateral inhibition was first demonstrated in the eyes of horseshoe crabs, which have eyes that are very different from the eyes of primates. When this notion is used to explain perceptual phenomena in humans, retinal ganglion cells of the on-center type are usually invoked. In contrast to horseshoe crabs' eyes, ganglion cells do not seem to directly inhibit each other; rather, their receptive fields (portions of the retina whose stimulation affects the cells' firing rate) are based on lateral interactions between other retinal neurons. It is well known that the receptive fields of on-center ganglion cells consist of a central disk whose stimulation by light increases the cell's firing rate, and a peripheral ring whose stimulation decreases the firing rate. These receptive fields are usually mathematically modeled as differences of two

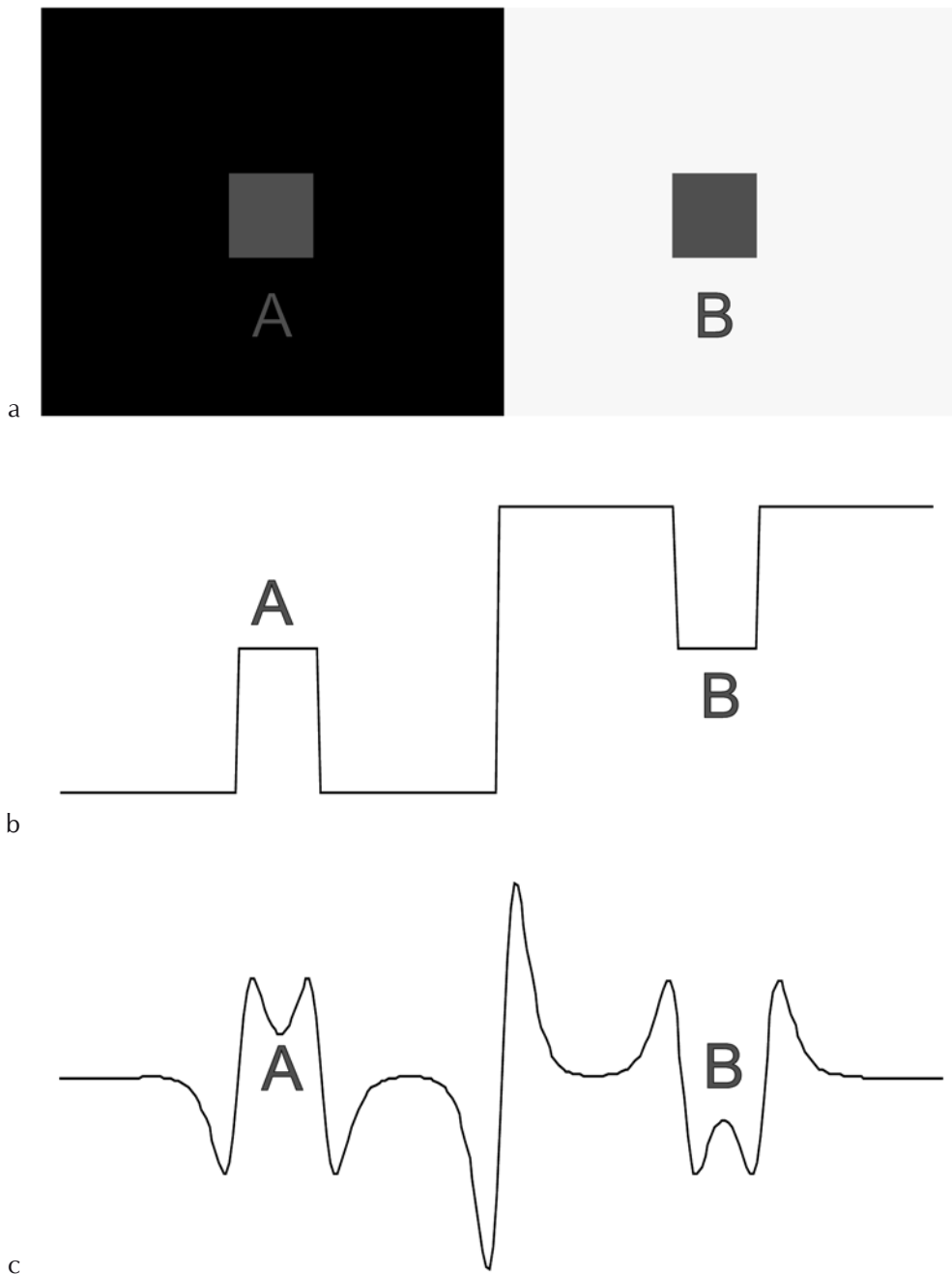


Figure 7. Illustration of lateral inhibition. (a) The simultaneous lightness contrast effect. (b) Sketch of luminance distribution along the mid-horizontal cross-section of (a). (c) Simulation of the response profile of on-center ganglion cells to the luminance distribution in (b).

Gaussian curves with equal areas, a tall narrow one for the center, and a low broad one for the periphery. It is relatively simple to simulate the reactions of such cells to various stimuli. A simulation of the reaction of a set of such cells to the simultaneous lightness contrast stimulus is presented in Figure 7c. For simplicity, the simulation is one-dimensional, that is, it corresponds to a set of cells arranged along a line. Figure 7b presents the corresponding horizontal one-dimen-

sional cross-section at mid-height of the luminance distribution of the stimulus depicted in Figure 7a. This example uses 1-D cross-sections, but this approach can be extended to 2-D profiles as well (e.g. in Grossberg & Todorović, 1988, and a number of later models in the literature).

The crucial aspects of the neural profile, with respect to the explanation of the context effect, are the levels of activity in sections A and B, corresponding to the target patch-

es. It can be seen that the average response in section A is larger than in section B. This is in accord with the percept that patch A looks lighter than patch B. To that extent, this simulation confirms the lateral inhibition account of the simultaneous lightness contrast effect. However, it also raises some serious concerns. The profile of the neural reaction, overall, is not in particularly good correspondence with the percept. In the neural output there are prominent oscillations corresponding to luminance edges in the stimulus input, involving an undershoot at the low-luminance side of the edge and an overshoot at the high-luminance side; however, the targets as well as the backgrounds are in fact perceived as mostly homogeneous surfaces (which indeed they are), with perhaps slight, narrow perceptual inhomogeneities at the edges, corresponding to Mach bands. Thus the response profile corresponds to the percept only in a rough first approximation, but appears to be in discord with it in many details. One way to remedy this problem is to introduce a filling-in mechanism that, roughly, performs an averaging process within edge-defined boundaries, and in this way eliminates the large inhomogeneities present in the profile above (Grossberg & Todorović, 1988). Another strategy is to introduce neural units with several different receptive field sizes (Blakeslee & McCourt, 1999).

A serious problem for the lateral inhibition account, as formulated above, is that although it may provide the neural basis for pure contrast effects, it is less suitable for explaining other lightness phenomena. Thus it has difficulties to account for the Wertheimer-Benary effect, White's effect, assimilation, and related phenomena.

A specific difficulty for the physiological strategy for explaining lightness phenomena is that currently there are few actual physiological data on these effects. One reason is that many neurons respond poorly to large homogeneously colored surfaces. However, a single cell recording study in monkeys (Rossi et al, 1995), using a simultaneous lightness contrast display, found that a subset of neurons in cortical area V1 showed activity levels that were in correlation with the human lightness percept. On the other hand, an fMRI study in humans by Cornelissen et al. (2006) found no correlation of recorded activity and percepts. In contrast, Perverzeva & Murray (2008) observed a close relationship between the fMRI signal and the amount of perceived lightness induction.

Finally, an important and rarely considered challenge for the physiological strategy is to spell out in more detail the relation between neural activity and conscious perception. In physiologically based accounts the stress is usually on the 'stimulo-neural' aspect, that is, how the incoming stimulus is processed in the visual nervous system. However, a complete explanation should also include the 'neuro-phenomenal' aspect, that is, how neural activation maps onto corresponding percepts.

In particular, the above account presupposes that stronger activation of neurons corresponds to higher levels of per-

ceived lightness. Note, though, that the simulated neurons belong to a special class, the on-center ganglion cells. The retina also contains off-center ganglion cells, whose receptive fields have inverse structure, compared to on-center neurons. In consequence, for such cells the simulated response profile to the simultaneous lightness contrast stimulus has a shape similar to Figure 7b, except that it is inverted. The correspondence is not exact, because off-center cells are not complete mirror images of on-center cells (Chichilnisky & Kalmar, 2002). However, the main point is that in the off-center cell profile the activity level corresponding to target A would be *lower* than for target B. If higher activity of off-center cells would correspond to higher levels of perceived lightness, then the output of off-center cells would be directly opposed to the simultaneous lightness contrast effect. Another possibility is that increased activity of off-center cells corresponds to increased perceived *darkness*, that is, decreased lightness levels (see Baumgartner, 1961). In this case their signal would not be in conflict but rather in accord with the signal of the on-center cells, with respect to lightness. Some empirical support for this notion is provided by studies that show that blocking the on-center cell activity results in deficits in registering light increments but not light decrements (Schiller, 1992). However, note that both on-center and off-center retinal neurons belong to very early levels of the visual system. We do not know the activity of which cells in the brain correspond to perceived lightness. To mention two extreme possibilities, is there a specific single class of final-level 'lightness neurons' in some cortical area, or is lightness perception based on distributed activity of many different types of cells throughout the visual system (see Todorović, 1987)? Such issues are still far from clear, and they are part of the largely unsolved general question of the relation of neural activity and conscious awareness, or, in philosophers' talk, the 'mind-body problem'. We may hope that a combination of careful phenomenology, sophisticated psychophysics, and ever-advancing neuro-physiological techniques may shed more empirical light on this perplexing and intriguing matter.

An example of the interpretational strategy: the illumination interpretation account

The optical signal that arrives at our eyes carries information about the outside world. However, due to various factors, this information is often ambiguous or distorted. Nevertheless, our perception of the world is usually accurate. One possible conclusion from this is that there exist perceptual mechanisms that operate upon the distorted input information and *interpret* it in light of additional available information or accumulated experience, thus providing us with more reliable knowledge about our surroundings. It has been suggested that many illusions are consequences of inappropriate applications of such interpretative mechanisms (Gregory, 1963). Such an explanatory strategy (which could

also be labeled as the *cognitive strategy*) postulates the existence of various quasi-intelligent, reasoning-like mechanisms to explain the illusory appearances.

A well known example involves the effects of linear perspective. According to the laws of geometrical optics, the size of the projection of an object upon the retina depends not only on its physical size but also on its distance from the observer; in consequence, objects of the same physical size but at different distances project images of different size on the retina. If our judgments of their objective size would rely only on their projective size, we would often make gross errors. Since we usually do not make such errors but are able to judge sizes of objects relatively independently from their distance (a phenomenon known as *size constancy*), it has been concluded that there are perceptual mechanisms that interpret the retinal size in view of other available information. One such purported mechanism of size constancy involves combining the retinal size of an object with information about its distance, and using this information to deduce its objective size as a conclusion; it should be noted that here the notions such as 'interpretation', 'deduction' and 'conclusion' are regarded as processes that do not presuppose any *conscious* cognitive operations of the perceiver. One popular explanation of the Müller-Lyer illusion, the details of which I will not go into here, proposes that such a 'taking distance into account' mechanism inappropriately interprets this configuration as involving perspective cues, from which it wrongly deduces that the two main lines are at different distances, and, since their projected sizes are the same, concludes that they must have different physical sizes.

A phenomenon analogous to size constancy is *lightness constancy*. It refers to the fact that in everyday life we encounter many objects under different illumination levels, but that nevertheless we can usually judge their reflectance relatively independently from illumination; for example we perceive a piece of chalk as white and a piece of coal as black, both under sunshine and in the shadow, although the coal in the sun may reflect more light than the chalk in the shade. One way to explain such phenomena is to propose the existence of a 'taking illumination into account' mechanism, which combines the information from object luminance reaching the retina with the information about object illumination, to deduce object reflectance. The important point for the present considerations is that such an illumination interpretation mechanism can be postulated to account not only for lightness constancy but also for simultaneous lightness contrast, in an explanation going back essentially to Helmholtz (see Kingdom, 1997). The assumption is that we perceive one half of Figures 4b or 7a as well illuminated and the other half as in shadow. If this is the case, then it can be deduced that the two targets, which have equal luminances but are under different illuminations, must have different reflectances. Thus the target in shadow (on dark background) must be light (though poorly lit), in order to reflect the same

amount of light as the target under high illumination (on white background), which must be dark (though well lit). Such an interpretative mechanism indeed correctly predicts which target in the simultaneous lightness contrast display will be perceived as lighter and which as darker.

This type of explanation has general appeal, because it is plausible that in the course of the evolution of the species or during the ontogenesis of the individual, organisms have developed special strategies for efficient registration of important, recurrent features in their environment. Furthermore, this sort of approach has the virtue of accounting both for the veridical performances of our sensory apparatus (perceptual constancies) as well as for non-veridical outputs (perceptual illusions). Finally, this type of approach, although quite different from the physiological strategy, shares with it the feature that it is a causal account, aiming to explain *why* perception is the way it is.

The 'taking illumination into account' explanation was also applied for other lightness effects, such as the one presented in Figure 8a (after Adelson, 1993). The two regions pointed at by arrows are equi-luminant (have the same luminance), but region A looks somewhat darker than region B. To explain this, note that there is an impression that the object in the figure is illuminated from above, and that its shape is such that region A belongs to a row of regions that receive stronger illumination than the row of regions to which B belongs. From this it can be deduced that region A must be darker than region B, in order for the two regions to reflect the same amount of light. The postulation of such a mechanism, that deduces that of two equi-luminant but differently illuminated regions one must be dark gray and well lit, whereas the other must be light gray and poorly lit, is based on the same reasoning as in the above Helmholtzian account of the simultaneous lightness contrast effect, except that here it has more face validity, because the impression of differential illumination is more salient.

However, a simple change in the geometry of the depicted figure puts this explanation into doubt. Compared with Figure 8a, in Figure 8b (after Todorović, 1997; see also Adelson, 2000), the two bottom rows of the figure are mirrored and shifted, so that the rows to which A and B belong are now perceived as parallel, and thus should be under the same illumination. However, the perceived difference between regions A and B in this figure is about the same as in Figure 8a, but it does not seem to be explainable elegantly by a 'taking illumination into account' mechanism, as in Figure 8a. From this it follows that the illumination interpretation account of Figure 8a is questionable as well, because according to it the lightness difference should have been eliminated or weakened in Figure 8b, but it was not.

Another example of the application of the illumination interpretation explanation, and how it can be questioned, is presented in Figure 9 (after Todorović, 2006). Figure 9a is a close replica of an image designed by Adelson (1995). Patches A and B have the same luminance, but A looks

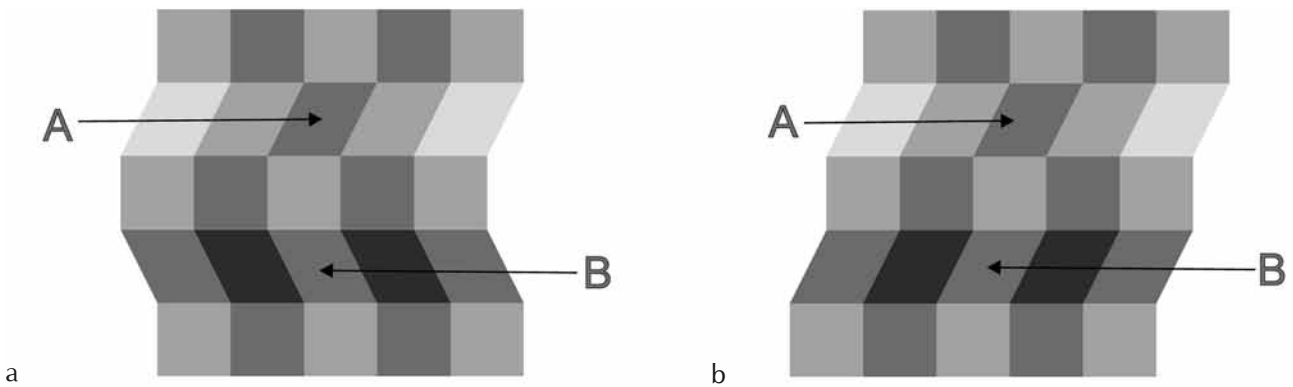


Figure 8. (a) The corrugated Mondrian. Patches A and B have the same luminance, but A looks darker, which can be explained by the illumination interpretation account. (b) The staircase Mondrian. The lightness difference between A and B is similar as in (a), contrary to the prediction of the illumination interpretation account.

darker than B. This can be explained by noting that patch B appears as located within the shadow cast by the cylinder, whereas patch A appears normally illuminated. As in the previous examples, the logic is that if two patches have the same luminance but are under different illumination, the one under higher illumination (patch A) must be darker than the one under lower illumination (patch B). A pictorial counter-argument to this explanation is presented in Figure 9b, in which the contrast between patches A and B does not appear to be much weaker than in Figure 9a. However, it can be seen that due to a number of manipulations in Figure 9b, described in detail in Todorović (2006), the sense that B is in shadow of the cylinder should be heavily compromised. The fact that the lightness illusion is not much diminished argues against the idea that an illumination interpretation process is responsible for it.

The final example of this type is presented in Figure 10 (after Todorović, 2006). Figure 10a depicts a shape that can be described as a curved staircase, painted with a checkered pattern. It contains horizontal and vertical parts ('steps'), connected by curved transition regions ('knees'). The point to note is that all patches on the steps indicated by arrows (both the horizontal ones denoted by A's and the vertical ones denoted by B's), have the same luminance, but appear to have different lightness. The explanation of this relatively strong lightness illusion within the illumination interpretation account is rather straightforward, and follows the same logic as in the previous examples. Observing this figure, one gets a clear impression of a curved, checkered surface, illuminated such that the horizontal steps receive more light than the vertical steps; note particularly that the graded luminance transitions along the knees fit very well within this

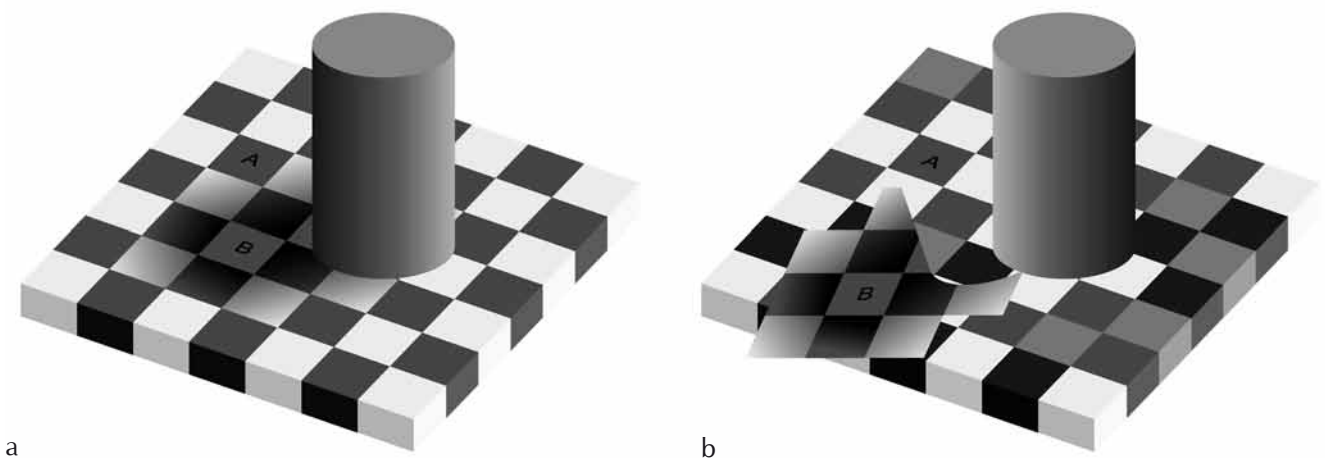


Figure 9. (a) The checkered shadow illusion. Patches A and B have the same luminance, but A looks darker. (b) Deconstructed checkered shadow. The lightness difference between A and B is similar as in (a), contrary to the prediction of the illumination interpretation account.

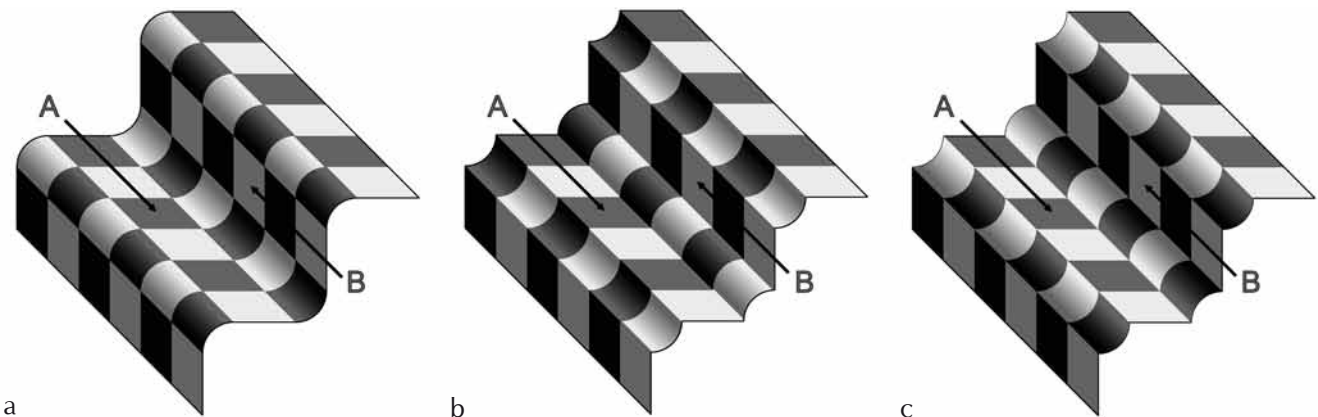


Figure 10. The checkered curved staircase and its variations. All 12 patches indicated by arrows have identical luminance. (a) Of the four patches pointed at by arrows, the two at the horizontal steps, denoted by A's, look clearly darker than the two at the vertical steps, denoted by B's. (b) The perceived difference of the four patches is smaller than in (a). (c) The perceived difference between the four patches is similar as in (a). See text for details.

interpretation. Since the indicated patches have the same luminance, it follows that the ones positioned on the horizontal steps must be darker than the ones positioned on the vertical steps, and this is indeed what is observed.

Figures 10b and 10c provide challenges to this account. Figure 10b contains the same horizontal and vertical steps as Figure 10a, but the knees are inverted both space-wise and luminance-wise. Inspection of this figure, and particularly of the knee luminances, indicates that the same illumination interpretation should apply as for Figure 10a. Nevertheless, the lightness differences between the A-patches and the B-patches appear much less salient than in Figure 10a. On the other hand, on Figure 10c the knees are only inverted space-wise (compared with Figure 10a), with the consequence that the illumination distribution upon the knees is not optically compatible with the illumination distribution upon the steps. Nevertheless, the lightness differences appear as salient as in Figure 10a (for details see Todorović, 2006).

Conclusion

In this paper I have presented four examples of contextual effects in visual perception, followed by discussions of three types of accounts of such effects. The typology of accounts does not pretend to be complete, nor do the accounts necessarily exclude each other. However, it is useful to consider the differences between frameworks within which various theories of these effects and theoretical account of perception in general, are often couched.

A simple example of each of the three types of accounts was considered in more detail, and their strong and weak points were discussed, with particular stress on the simultaneous lightness contrast effect. Although the three example

accounts (based on contrast, lateral inhibition, and illumination interpretation) may have initially appeared plausible, when submitted to more detailed analyses, each was shown to exhibit important and instructive shortcomings. However, this does not mean that these notions are without merit for the explanation of context effects. They can be and were embedded as constituents of many complex theories of these effects. However, an adequate examination of such more encompassing accounts, and there are quite a few, is beyond the scope of a brief introductory conceptual overview paper.

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