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Judgments of Time to Contact are Affected by Rate of Appearance of Visible Texture

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Abstract

More fine-grained texture becomes visible if the distance between an observer and an object or surface is reduced. This article illustrates with a schematic example that the inverse rate of the relative appearance of visible texture provides information about time to contact if the observer has a constant visual acuity and the texture has a certain scale-independent structure. An experiment is reported in which texture appearance was manipulated. Participants were asked to make forced-choice time-to-contact judgments. A small but significant effect indicates that the judgments were affected by the rate of appearance of the texture. It is concluded that observers use this type of information.

Keywords: fractals, nesting principle, perception, tau, visual acuity
Judgments of Time to Contact are Affected by Rate of Appearance of Visible Texture

Time to contact is defined as the time remaining until an observer and an object or surface make contact if current velocities are maintained. Time to contact is of crucial importance for the control of prospective actions. It is therefore not surprising that a large body of research exists concerning the optical information that supports the perception of this property. The most-studied informational variable is $\tau$, defined as the ratio of optical size, $\theta$, over optical expansion, $\dot{\theta}$ (Lee & Reddish, 1981; Lee, Young, Reddish, Lough, & Clayton, 1983; cf. Savelsbergh, Whiting, & Bootsma, 1991). Given several boundary conditions, $\tau$ specifies time to contact. Other informational variables that have been considered in relation to the perception of time to contact include optical size by itself and optical expansion by itself (Michaels, Zeinstra, & Oudejans, 2001; van der Kamp, Savelsbergh, & Smeets, 1997; cf. Bootsma & Craig, 2002; López-Molinier & Bonnet, 2002; Tresilian, 1999).

We consider an alternative source of information: The becoming visible of fine-grained texture. Objects and surfaces are textured at many scales, and perceptual systems are sensitive only to texture at a particular subscale. Some texture elements are too large to be visible and others are too small. The range of texture elements that a perceptual system can detect depends on the distance of the object or surface with respect to the observer: at shorter distances, more fine-grained elements are visible (Gibson, 1979/1986, pp. 108). Hence, the appearance of fine-grained texture implies the approach of an object or surface. It is intuitively clear that the rate at which fine-grained texture
Time to Contact and Texture Appearance

appears is related to speed of approach and to time to contact. Let us analyze this relation in more detail.

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Insert Figure 1 about here

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Figure 1a presents a texture with similarity over scales: One texture element consists of subelements, which again consist of subelements, etc. Figure 1b illustrates that a perceptual system with a constant visual acuity might be able to distinguish four texture elements in each dimension from a short distance, two from a larger distance, and one from a yet larger distance. In this example the number of visible elements, $\alpha$, is given by the ratio of the optical size of the object, $\theta$, and the visual acuity of the observer, $\delta$, at least for integer values of the ratio. If, slightly more generally, we assume that $\alpha$ is proportional to $\theta/\delta$, then we have:

$$\frac{\alpha}{\bar{\alpha}} = \frac{k\theta/\delta}{k\bar{\theta}/\delta} = \frac{\theta}{\bar{\theta}} = \tau,$$

(1)

in which $k$ is a constant. According to this equation the ratio $\alpha/\bar{\alpha}$ and $\tau$ are specific to each other, meaning that $\alpha/\bar{\alpha}$ provides the same information about time to contact as $\tau$.

The above-indicated specificity between $\alpha/\bar{\alpha}$ and time to contact is based on several assumptions, or constraints (Runeson, 1988; cf. Jacobs, Runeson, & Andersson, 2001), including: (1) the object’s texture has the previously described scale-independent structure or a similar one, and (2) the visual acuity of the observer is constant in the considered part of the visual scene. The extensive literature on fractals provides some
support for (1), which is also closely related to Gibson’s (1979/1986) principles of nesting. Furthermore, useful information related to the appearance of texture might exist even if these assumptions are not strictly tenable. In that case, however, the relation between the appearance of texture and time to contact should not be expected to be as apparently simple as indicated in Equation 1.

The aim of this study is to test whether the becoming visible of fine-grained texture affects the perception of time to contact. We report an experiment in which participants were asked to judge which of two approaching spheres would arrive first. Lines of longitude and latitude gradually appeared during the natural expansion of the simulated spheres. The rate of appearance of these texture elements was manipulated as illustrated in Figure 2: The upper part of the figure shows an approach with a faster appearance of the texture than the lower part. We hypothesize that spheres with a faster texture appearance are more likely to be perceived as arriving first.

The example in Figure 3 illustrates the effect of our manipulation on the ratio $\alpha/\dot{\alpha}$. With a slower texture appearance $\alpha/\dot{\alpha}$ indicates longer than veridical times to contact (dash-dotted curve), and with a faster texture appearance shorter times to contact are indicated (dashed curve). This was true for all approaches used in the experiment. The precise values of $\alpha/\dot{\alpha}$, however, are different for different approaches. For the majority of the approaches used in the experiment the dash-dotted and dashed curves would have been further apart than the ones shown in Figure 3.
Method

Participants

Forty-one students of the Autonomous University of Madrid (UAM) participated in the experiment. They received a 2 gigabyte pendrive for their participation. Their ages ranged from 19 to 30 years with a mean of 22.9 years. Most of them participated in a 30-min long, non-related experiment prior to start of this one. All of them were naive with respect to the purpose of the experiment. Informed consent was obtained prior to testing.

Apparatus

Stimuli were presented on a 17”’ TFT monitor (1024 x 768 pixels). A chinrest was used to stabilize the head of participants at a distance of 50 cm from the monitor. Responses were registered with a keyboard.

Stimuli and design

Time-to-Contact Differences. The stimulus for each trial consisted of a pair of approaching spheres that disappeared shortly before reaching the observer. The difference in the respective times to contact ranged from -.29 to .29 s in steps of .02 s (a negative difference indicates that the left sphere had a shorter time to contact). Each of these 30 values was used twice: once with the left sphere having a faster texture appearance and once with the right sphere having a faster texture appearance. The experiment hence consisted of 60 trials, presented in a random order.
Texture Appearance. Two longitude and latitude lines were visible on each sphere at the moment at which the spheres appeared (see left side of Figure 2). During the approach the distance between these lines gradually increased due to the expansion of the projected spheres. New longitude and latitude lines were added to the spheres as the screen distance between the already visible ones increased. The critical manipulation of the experiment—which can be interpreted as a violation of the assumptions of Equation 1—was that for one of the spheres the new longitude and latitude lines were added more quickly than for the other.

We define $D$ as the distance on the screen (at the center of the sphere) between successive longitude or latitude lines and $D_{\text{min}}$ as the smallest to-be-used value of $D$. Adding a set of lines between the currently visible ones reduces $D$ by half. Fully visible lines were added at the moments in the approach at which $D$ was twice $D_{\text{min}}$, meaning that reducing $D$ by half would still yield a value of $D$ larger than or equal to $D_{\text{min}}$. At the start of the approach the value $D_{\text{min}}$ of a sphere was set at the actual $D$ value at that moment ($D_{\text{start}}$). For the sphere with the faster texture appearance $D_{\text{min}}$ was reduced during the approach: $D_{\text{min}}$ at occlusion was $0.5 \times D_{\text{start}}$. For the sphere with the slower texture appearance $D_{\text{min}}$ at the end of the approach was $1.5 \times D_{\text{start}}$. The change in $D_{\text{min}}$ during the approaches was quadratic: $D_{\text{min}} = D_{\text{start}} \times (1 \pm 0.5 \times t^2)$ with $t = (TTC_{\text{start}} - TTC)/(TTC_{\text{start}} - TTC_{\text{occlusion}})$. This led to reasonably smooth and distinguishable $\alpha/\dot{\alpha}$ values (look back to the example in Figure 3).

The previous description concerned the moments at which the newly included longitude and latitude lines were fully visible. However, these lines did not appear abruptly; their visibility gradually increased from 0 % (not yet presented) to 100 % (fully
visible). From the moment at which one set of fully visible lines was added to the
moment at which the next set of fully visible lines was added, the ratio $D/D_{\text{min}}$ gradually
increased from 1 to 2, approximately. We used the value $D/D_{\text{min}}$ to pre-present that next
set of lines with a reduced intensity. When $D/D_{\text{min}}$ was 1 these lines were pre-presented
with an intensity of 0 % (not yet presented) and this intensity gradually increased
reaching a visibility of 100 % as $D/D_{\text{min}}$ reached a value of 2.

Other Variables. The following values were randomly chosen on each trial, from
the indicated intervals. The time to contact of the first-arriving sphere at the moment that
the spheres disappeared was chosen from the interval between .2 and .4 s. The spheres
were visible for a period chosen from the interval between .5 and 1.0 s. The spheres,
which had a fixed 3-d radius of 15 cm, approached the point of observation with a
constant speed between 5 and 10 m/s. At the start of the approach the horizontal screen-
distance between the center of the left sphere and the center of the screen was chosen
from the interval between -10 and -5 cm; this interval ranged from 5 to 10 cm for the
right sphere. The vertical distance to the center of the screen, again at the start of the
approach, ranged from -8 to 8 cm for both spheres, determined independently of each
other. The spheres were presented as red, blue, or green lines on a white background. The
colour was never the same for both spheres: One of the 6 possible colour combinations
(blue/red, blue/green, red/green, and the inverses) was randomly assigned to each trial.
The spheres consisted of an outline and the projections of the visible parts of the
longitude and latitude lines. The 3-d longitude and latitude lines were symmetrical with
regard to the frontoparallel, midsagital, and transverse planes. This means that the
observers saw the spheres slightly from below or above and from the side, depending on
the location of the spheres (this in contrast to the projections in Figure 2).

Procedure

Before the actual experiment participants were told that pairs of approaching
objects would appear on the screen and that these objects would disappear before
reaching their frontoparallel plane. They were asked to judge which object would reach
them first on each of the 60 trials. Participants pushed the †-key to start a trial, after
which a fixation cross (.50 cm wide x .53 cm high) was presented in the middle of the
screen. After 1 s the fixation cross disappeared and the approaching spheres appeared,
one on each side of the screen. Once the spheres had disappeared participants entered
their response with the ← or → key. Half a second later a message announced the start of
the next trial. The experiment was completed in about 10 min.

Results

The hypothesis that motivated this experiment was that spheres with a faster-
appearing texture are more often perceived as arriving first. As a first test of this
hypothesis we computed the percentage of right-first judgments for trials in which the
right sphere had a faster texture appearance than the left one and for trials in which the
right sphere had a slower texture appearance. Figure 4 presents these percentages. Indeed,
the right sphere was more often judged to arrive first when it had a faster texture
appearance. A paired t-test confirmed this difference: \( t(40) = 4.0, p<.001 \).

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Insert Figure 4 about here
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Figure 5 shows the data in more detail. The figure shows logistic curves fitted to the data. The curves represent the proportion of right-first responses as a function of the time-to-contact difference for trials on which the right sphere had a faster texture appearance (continuous curve) and for trials on which the left sphere had a faster texture appearance (dashed curve). The continuous curve lies higher than the dotted one. This indicates, again, that more right-first responses occurred for trials in which the right sphere had a faster texture appearance. To statistically test this finding we fitted similar logistic curves to the data of each individual and performed paired $t$-tests on the slopes and intercepts of these curves. The difference between the intercepts was significant, $t(40)=2.9, p=.005$, confirming the difference between the curves observed in Figure 5. The slopes did not differ significantly: $t(40)=.70, p=.49$.²

The effect of the experimental manipulation was not as large as the effect predicted by the use of $\alpha/\dot{\alpha}$ alone. According to our calculations that used disks instead of spheres (see also Footnote 1 and Figure 3), the value of $\alpha/\dot{\alpha}$ at occlusion was smaller for the object with the faster texture appearance than for the other object in 99.5% of the trials. If one assumes that the moment of occlusion is indeed the relevant moment, then this means that the use of $\alpha/\dot{\alpha}$ alone would have predicted participants to judge the sphere with the faster texture appearance as arriving first on 99.5% of the trials. This was not found to be the case.

Discussion
Fine-grained texture becomes distinguishable to observers when the distance between the observer and an object or surface is reduced. In the introduction of this article we have illustrated that the inverse of the relative rate at which the elements become distinguishable specifies time to contact (Equation 1; see also the assumptions that follow the equation). In our experiment, approaching spheres with more rapidly appearing longitude and latitude lines were more often judged as arriving first than spheres with more slowly appearing longitude and latitude lines. We hence conclude that observers are sensitive to information related to the becoming visible of texture.

During approaches in more ecologically valid environments, texture should be expected to appear in a stochastically regular rather than perfectly regular way, and at the scale of the visible acuity of perceivers rather than at the larger scale of the distance between consecutive lines in our experiment. Our reasoning is based on the assumption that these differences are not crucial. Also note that other interpretations of our result are possible. More texture was visible at the end of the approaches in the condition with a faster texture appearance than in the condition with a slower texture appearance. It is possible that the amount of visible texture affects perceived size and that perceived time to contact is affected by this change in perceived size rather than by the rate of texture appearance.³

Our result is consistent with the more general claim that time to contact is perceived more accurately for textured objects than for objects without texture. This claim has been made, for instance, by López-Moliner, Brenner, and Smeets (2007), although these authors made the claim for different reasons than we do. Also of relevance is the work of Vincent and Regan (1997), who performed an experiment in which the
expansion of texture elements on a target was manipulated independently of the expansion of the outline of the target (see their Figure 1). Vincent and Regan showed that the expansion of texture elements affects time-to-contact judgments (cf. Gray & Regan, 1999). Even so, these authors did not simulate the becoming visible of fine-grained elements. This means that their finding is different than ours. The difference between our experimental conditions was the rate of appearance of longitude and latitude lines; once the lines were visible their projections evolved in identical ways.

To summarize, the rate of appearance of texture seems to affect the perception of time to contact, and this informational variable is different from the variables considered in the texture-related work of Vincent and Regan (1997) and Gray and Regan (1999) and from the variables considered in other time-to-contact work of, for instance, DeLucia, Kaiser, Bush, Meyer, and Sweet (2003) or Kim and Grocki (2006). This brings us to a final, more general question: How can one achieve a parsimonious theory if so many informational variables appear to be relevant? As a tentative answer to this questions we propose to describe all relevant variables in a low dimensional manifold and to search for lawfulness in how people continuously converge toward optimal variables in that manifold (Jacobs & Michaels, 2007; Jacobs, Silva, & Calvo, 2009; Michaels, Arzamarski, Isenhower, & Jacobs, 2008).
References


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Footnotes

1. The curves shown in Figure 3 were calculated for an approaching disk, assuming this to be a reasonable approximation of the frontal part of the spheres used in the experiment. The calculations would have been more complicated for a sphere because for a sphere the line of sight cannot be assumed to be orthogonal to the surface and because fine-grained texture goes out of sight at the occluding edge of an approaching sphere. Otherwise the texture-appearance conditions were computed as in the experiment.

2. The logistic curve is defined by \( y = \frac{1}{1 + \exp(-a - bx)} \), in which \( a \) is the intercept and \( b \) the slope. We fitted the curves using a least-squares method. Finite ranges of slopes and intercepts were used to fit the data of individuals. In several cases the best fits were observed for slopes and/or intercepts that lay at the extremes of these ranges. Even so, similar overall results were obtained with different ranges.

3. Let us mention that this interpretation is based on hypothetical internal constructs and hence is more representational than direct in a Gibsonian sense (Gibson, 1979; cf. Calvo Garzón, 2008).
Figure Captions

Figure 1. A: Schematic representation of scale-independent texture. An object (square) is shown as consisting of a single texture element (top). From each row to the next, the number of represented texture elements is doubled (for each dimension). B: If visual acuity ($\delta$) is constant, then the number of distinguishable texture elements depends on the viewing distance. From a short distance four texture elements of this object might be distinguishable (left), whereas two elements (middle) and one element (right) might be distinguishable from longer distances. Note that only one dimension of the object is considered in B.

Figure 2. Time-frozen images that illustrate the fast and slow conditions at three time-to-contact (TTC) values. The approaches in the experiment had random differences in position, speed, and colour that are not shown in the figure, and the images in the figure are reduced in size with respect to the screen size of the ones used in the experiment.

Figure 3. Values of $\alpha/\dot{\alpha}$ as a function of time to contact for an approaching disk that is visible from a time-to-contact value of 1.2 s until a time-to-contact value of .2 s. Dash-dotted curve = slow texture appearance. Dashed curve = fast texture appearance. The straight diagonal line represents veridical time-to-contact values.

Figure 4. Percentage of right-sphere-arrives-first responses as a function of texture-appearance condition. The error bars indicate standard errors.
Figure 5. Proportion of right-sphere-arrives-first responses as a function of time-to-contact difference and texture appearance condition. Negative values on the horizontal axis indicate that the left sphere would have arrived first.
Figure 1
Time to Contact and Texture Appearance

Figure 2

Fast Texture Appearance

Slow Texture Appearance

TTC = 1.05  TTC = .68  TTC = .3
Figure 3
Figure 4

![Chart showing time to contact and texture appearance comparison between faster texture appearance left and right. The chart indicates a higher percentage for faster texture appearance right.]
Figure 5

![Graph showing the relationship between Time to Contact (TTC) and Texture Appearance, with curves indicating the proportion of faster texture appearances for left and right objects over time.](image-url)