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TEMPORAL ORDER JUDGEMENTS – A SENSITIVE MEASURE FOR MEASURING PERCEPTUAL LATENCY?

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Abstract

Temporal order judgments (TOJs) have been used for demonstrating the facilitating effect of attention on information processing - prior entry. Prior entry is a robust, often large effect. Besides attention, other factors shorten perceptual latency, for instance stimulus saliency, action affordances of an object, or threatening objects. The expectable size for these effects is far smaller than that usually obtained for prior entry. Some effects might consist of only a few milliseconds. But are TOJs sensitive enough for detecting such small effects? For answering this question, we tested whether objects highly associated with a certain color are perceived earlier. In a four-alternative TOJ, including a "simultaneous" and "uncertain" category, we found a small advantage for high color diagnostic objects. This indicates high sensitivity of the TOJ task. We also found that "simultaneous" judgments were most sensitive. This is important for the debate on the usefulness of order vs. simultaneous judgments.

Imagine a thunderstorm. Usually you will hear the thunder after you have seen the lightning. Probably many of you have used the temporal delay between perception of lightning and thunder for estimating the distance from the eye of the thunderstorm. Although this temporal delay certainly reflects the difference in propagation speeds of light and sound, it could also been seen as a difference in perceptual latencies for both environmental events. Thus, perceptual latency refers to the temporal interval between the onset of a stimulus and its perception. Differences in perceptual latencies are of peculiar interest for psychologists because they reflect processing advantages for certain stimuli or stimuli features and can thereby lead us to a better understanding of human information processing. For instance, it is well documented that attention shortens perceptual latency of attended stimuli (prior entry; for a recent overview see Spence & Parise, 2010). This falls into place with the interpretation of attention as a selection mechanism that helps humans to prioritize relevant information over irrelevant information, in this case by making them earlier available. Additional examples for relevant information that is prioritized by shorter perceptual latencies are salient objects (Lester, Hecht & Vecera, 2009), objects with high action affordances (Roberts & Humphreys, 2010), objects compatible with a required motor response (simon effect, Lu & Proctor, 1995), or objects surrounded by congruent context stimuli (Eriksen & Schultz, 1979).

Since some of these latency advantages are very small - sometimes not larger than a few milliseconds- a very sensitive measure is necessary for detecting those effects. Most of the smallest latency advantages, as for instance the simon effect, are assessed by reaction times (RTs). RTs, however, have one major disadvantage. Additionally to the perceptual latency of a stimulus, they include a motor component (e.g. Jaśkowski, 1999). Participants have to make a specified motor response as fast as possible after detecting a target stimulus. Therefore the RT reflects the time until target detection and additionally the time necessary for planning and execution of the required motor response. An RT difference might therefore reflect not only a difference in perceptual processing speed but also a difference in the speed of motor processing. By contrast, latency advantages assessed by temporal order judgments (TOJs) are free from motor processes because here latency differences are derived from *unspeeded* judgments about temporal order (for a more detailed description of TOJs see the paragraph on TOJ method). Due to their lack of a motor component, TOJs probably give a purer estimation of the latency advantages than RT differences. Since latency advantages assessed by this task (e.g. prior entry) are usually large and robust effects, it is a crucial question whether TOJs, which have the advantage of being free from motor processes, are sensitive enough for detecting small effects of perceptual facilitation, too. Answering this question is the aim of the present study.

For investigating this question, we chose a stimulus feature which will probably result in small effects of perceptual facilitation, color diagnosticity. Tanaka and Presnell (1999) revealed that color plays a role in object recognition if a given stimulus is highly associated with a color (e.g. a red fire engine). They term these objects high color diagnostic (HCD) objects in comparison to low color diagnostic objects (LCD) which are not associated with a color. For several RT based tasks (classification, verification, naming) Tanaka and Presnell revealed latency advantages for naturally (congruently) colored HCD objects in comparison to gray scale or incongruently colored HCD objects. However they did not find such advantages for LCD objects. Additionally, in a verification task (Experiment 4) they revealed an advantage of 27 ms for HCD objects in comparison to LCD objects. For naturally colored objects, this difference was reduced to 18 ms, for achromatic objects the difference was 10 ms. In a classification task, observers were slightly faster to classify naturally colored HCD objects in comparison to naturally colored LCD objects (10 ms). As latency differences assessed by RTs are usually larger as those assessed by TOJs (Jaśkowski, 1999), we can actually expect an even smaller advantage, probably between a few and 10 milliseconds, for naturally colored HCD objects in comparison to naturally colored LCD objects.

We will now shortly explain the TOJ method in more detail and how perceptual facilitation can be assessed by it. In the frequent binary TOJ task, observers judge which of two target stimuli presented in succession appeared first. Between trials, the temporal delay between the two targets is varied. Perceptual facilitation is evident in a shift of the point of subjective simultaneity (PSS) which is the temporal delay at which both possible order judgments are given equally often. The PSS shifts usually from physical simultaneity under control conditions towards a temporal delay at which both targets were actually displayed in succession in experimental conditions. The shift's size quantifies the latency advantage. In a binary TOJ, observers are forced to choose one of the two possible orders and cannot indicate that both targets appeared simultaneously or that they are uncertain about their temporal relation. It is possible that forcing observers to guess an order if they actually have another temporal percept conceals the small latency advantages we are interested in. We therefore chose a probably more sensitive version of TOJ - a four-alternative TOJ with additional judgment alternatives "simultaneous" and "uncertain". We chose this version because we wanted to give the TOJ the best chance to reveal the small latency effect for naturally colored HCD objects. Besides its probably better sensitivity, the described four-alternative TOJ has the additional advantage that it allows us to compute perceptual facilitation in different ways - from order and "simultaneous" judgments. In "simultaneous" judgments, perceptual facilitation is also evident in a shift of the PSS, but here the PSS represents the temporal delay at which observers judge "simultaneous" most frequently. Furthermore, a comparison between the latency advantages derived from the order judgments and "simultaneous" judgments might shed more light on the current debate whether judgments of temporal order or judgments of simultaneity are the better measure to reveal perceptual latencies (e.g. van Eijk, Kohlrausch, Juola & van de Par, 2008). We will turn to this question in more detail in the discussion. To summarize our hypotheses, we expected a small advantage in perceptual latency for naturally colored HCD objects in comparison to naturally colored LCD objects. And we expected to find this effect in the order judgments as well as in the simultaneous judgments.

Method

Twenty-seven students of Paderborn University (14 male, mean age = 27 years) all with normal or corrected to normal vision and unimpaired color vision, took part in the experiment. Stimuli were colored pictures of ten high color diagnostic and ten low color diagnostic stimuli chosen from the high and low color diagnostic objects identified by a feature listing task in Tanaka and Presnell, (Experiment 1). The HCD objects were banana, broccoli, fire engine, carrot, lettuce, lime, corncob, radish, stop sign and lemon. The LCD objects were bird, table, chair, screwdriver, saw, lamp, dog, hammer, guitar and fish.

Participants sat in a dimly lit room. Their head was fixed by a chin rest. They were instructed to look at the fixation cross in the middle of the screen. After a random interval (800 to 1200 ms) the first target stimulus appeared on the screen. The first target was displayed either left or right and either above or below fixation, approximately 6.3° apart from fixation on a horizontal axis. After a temporal interval varying from zero to 136 ms in steps of 34 ms the second target appeared at the opposite location. Whether the first target appeared right or left of fixation was chosen randomly. In experimental trials one of the targets was LCD, the other HCD. In control trials both targets were either LCD or HCD. The targets were deleted after 34 ms. At the end of each trial a display with all 20 items appeared on the screen and participants first chose which two objects they had seen and then indicated by a four-alternative temporal order judgment whether (1) Object A was presented first (2) Object B was presented first (3) both objects were presented simultaneously or (4) that they were uncertain about the temporal order of the stimuli.

Results

Analysis of the order judgments.

Order judgments (e.g. “guitar first”) were re-coded into judgment categories of interest “HCD object first” and “LCD object first”. For each participant judgment frequencies of order judgments were counted separately for each combination of temporal delay/ condition. For estimating perceptual facilitation, these judgment frequencies were then fitted by a logistic function (Logit analysis, Finney, 1971). Perceptual facilitation was calculated as the difference between the 0.5 thresholds of control and experimental trials separately for each order judgment. The 0.5 threshold constitutes the temporal delay at which a respective judgment was chosen in half of the trials. Since they could not discriminate the order of the target stimuli before or not even at the largest temporal delay, data of three observers were excluded from the analysis. T-tests for difference values of 0.5 thresholds between control and experimental trials revealed a significant advantage of $M = 5$ ms for HCD stimuli in the order judgment “LCD object first”, $t(23) = 1.9$, $p <.05$ (one-tailed), $d = 0.81$, but no advantage for the order judgment “HCD object first”, $M = 0.5$ ms, $t(23) = 0.18$, $p = .86$, $d = 0.07$. (see Figure 1). Note, that although the advantage for “HCD object first” was not significant, it goes numerically in the correct direction. Furthermore DL (interquartile range of the psychometric function) was computed as measure of discrimination accuracy. There were no differences in discrimination accuracy, all t < 1. DLs were 36 ms (HCD control trials), 37 ms (HCD experimental trials), 34 ms (LCD control trials) and 35 ms (LCD experimental trials).

Analysis of the simultaneous judgments

Since observers should judge “simultaneous” most often for small temporal delays and less often for larger temporal delays, we fitted the simultaneous judgments of each with a non-normalized Gaussian distribution

$$y = a*\exp(-(x-x0)^2/(2*s^2)) \quad (1)$$

in which a represents the distribution’s maximum. x0 represents the location of this maximum on the x-axis, that means the PSS, and s represent the standard deviation of the distribution, which can be used as measure of temporal resolution and is an equivalent of the DL parameter in TOJ. Because they never judged “simultaneous” in experimental trials, the data of two participants had to be excluded from this analysis. The chosen distribution was well able to fit the “simultaneous” judgments for control trials, $R = .97$, $t(24) = 83$, $p < .001$, $d = 34.61$, and experimental trials, $R = .98$, $t(24) = 181$ $p < .001$, $d = 75.48$. R represents the Pearson correlation between data and distribution. As expected, the PSS assessed by “simultaneous” judgments was shifted by 6 ms in favor of HCD objects, $t(24) = 6.01$, $p < .001$, $d = 2.51$. In contrast to the discrimination accuracy of the order judgments, discrimination accuracy respectively temporal resolution was impaired for experimental trials, as s was larger for experimental trials than for control trials (control trials, $M = 12$ ms vs. $M = 16$ ms, $t(24) = -4.7$, $p < .001$, $d = 2.04$). For a comparison of the latency advantages see Fig. 1.

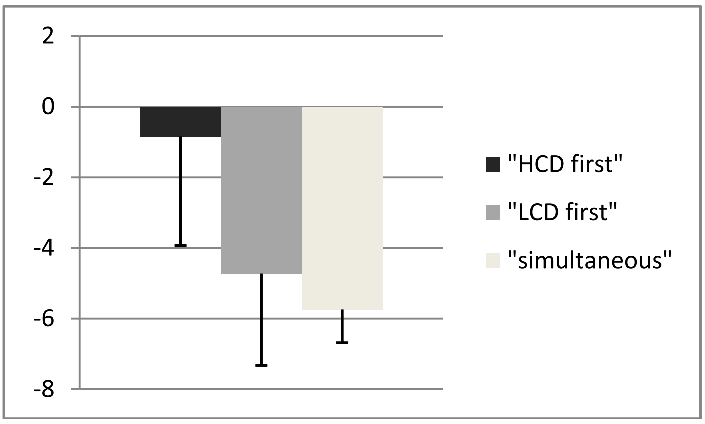

Fig. 1. displays the latency advantages for both order judgments and “simultaneous” judgments in ms. Note that negative numbers indicate an advantage for HCD objects, whereas positive numbers would indicate an advantage for LCD objects. Error bars display the standard error of the mean.

Discussion

Perceptual latencies assessed by TOJs have the major advantage of being free from motor processes, providing thereby a purer estimate of perceptual facilitation. Since most effects of perceptual facilitation assessed by TOJs, as for instance prior entry, are large and robust effects, it is a crucial question whether TOJs are sensitive enough for detecting small effects as well. Our results demonstrated high sensitivity of the four-alternative TOJ: We found small advantages for HCD objects in one of the order judgments (5 ms) and in the "simultaneous" judgments (6 ms). Two recent studies demonstrated that binary TOJs are sensitive enough for detecting medium effects: Lester, Hecht and Vecera (2009) found a 10 ms advantage for salient objects and Roberts and Humphreys (2010) found a 10 ms respectively 13 ms advantage for active objects correctly positioned for action. West, Anderson and Pratt (2009) revealed small latency advantages for motivationally relevant stimuli, comparable in size with the effects found in the present study. Although this might indicate high sensitivity of binary TOJs as well, this result should be interpreted cautiously. Visual inspection revealed relatively noisy psychometric functions and unfortunately no goodness of fit data were provided.

The latency advantage did only show up in one of the order judgments. With 0.5 ms it was numerically absent in the other order judgment. An effect of only a few ms might easily be missed in a certain condition. Also, the amount of "simultaneous" and "uncertain" judgments in a certain condition influence the possible number of order judgments. Finally, the advantage might be easier to detect when the LCD objects leads and the HCD object catches up than if the HCD object leads. On the basis of the present data, we can not decide which of these explanations holds.

We will now turn to a possible alternative explanation of our results. A frequent objection against TOJs is that they do not measure perceptual facilitation but- at least partially- a bias in decision criteria (e.g. Pashler, 1998). For instance, the latency advantage for HCD objects would not reflect that observers have perceived these objects earlier, but that their decision was biased in favor of HCD objects. Such a decision bias would be especially likely if the task was difficult, that is for small temporal delays between the targets. For two reasons, however, a response bias seems not likely in the present study. First, observers gave their judgment about which of two specific objects (e.g. a lemon or a table) they perceived first and not about the categories of interest (HCD or LCD objects). Second, the possibility to judge "uncertain" should have reduced a possible bias favoring HCD objects under condition when observers were unsure about their answer.

Up to the present paragraph we have argued that our results show a latency advantage of HCD objects, but color diagnosticity is not the only dimension that distinguishes HCD and LCD objects. The majority of HCD targets are natural objects as for instance a lettuce, whereas the majority LCD objects were artificial objects like a table. Thus, we cannot decide with certainty whether we found a perceptual advantage for HCD objects or for natural objects in comparison to artificial ones. Since, this is not primarily relevant for the aim of our study -Are TOJs a sensitive measure or not?- we leave this question to future research.

Do judgments of order or simultaneity provide the better estimate for assessing perceptual latencies? Recently many authors argued that judging the temporal order of two stimuli *or* judging whether two stimuli appeared simultaneous vs. in succession (binary SJ) refer -at least partially- to different underlying temporal mechanisms (e.g. Shore, Gray, Spry & Spence, 2005; van Eijk, Kohlrausch, Juola & van de Par, 2008; Weiß & Scharlau, 2010). But they disagree whether TOJs or SJs are the more preferable measure. For instance, Shore et al. assumed that TOJs are more sensitive because they need more information than the "simpler" SJs. For making a SJ, only information about simultaneity would be necessary whereas for a TOJ information of non-simultaneity and order would be necessary. By contrast, van Eijk et al. argued that binary SJs or ternary TOJs (order judgments plus "simultaneous") should usually be preferred -depending on the studys' objective- because these measures provided more stable PSS estimates. In an audio-visual paradigm they found a high correlation between estimates derived from binary SJs and ternary TOJs, but no correlation between binary TOJs and SJs. Our results are in accordance with the results of van Eijk et al. and indicate high sensitivity of more than binary TOJs. Considering the results of van Eijk et al. and that we found a larger advantage in "simultaneous" judgments it would be interesting for future research to investigate whether a binary SJ is as sensitive for detecting small effects in perceptual facilitation as a four-alternative TOJ.

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