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ORIGINAL ARTICLE

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Perceptual latency priming: A measure of attentional facilitation

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Abstract The present paper reviews recent research on perceptual latency priming (PLP). PLP is the relative latency advantage—earlier perception—of a visual stimulus that is preceded by another, masked stimulus at its location. The first stimulus attracts attention which accelerates perception of the second stimulus. This facilitation arises even if the first stimulus is visually backward-masked by the second one. The paper summarises research on temporal and spatial properties of PLP and the question whether intentions mediate shifts of attention to external events. Possible sources of PLP besides visuo-spatial attention are discussed. Finally, I give a review of feedforward and reentrant models of PLP and compare them to the empirical evidence.

Introduction

Among the initial topics of experimental psychological research, one of the most interesting—both in theory and history—is the notion of *prior entry*. According to Titchener's classical definition of prior entry, the "stimulus, for which we are predisposed, requires less time than a like stimulus, to produce its full conscious effect. Or, in popular terms, the object of attention comes to consciousness more quickly than the objects we are not attending to" (Titchener, 1908, p. 251). In fact, prior entry had been discovered and experimentally investigated within astronomy even prior to the rising of experimental psychology (e.g., Bessel, 1838; Mitchel, 1858; summaries in Boring, 1929; Sanford, 1888). Few decades later, the phenomenon became very popular in early experimental psychology, especially in the laboratory of Wundt. He was also the first to ascribe prior entry to attention (Wundt, 1887). Shortly after, however, interest in prior entry (as well as attention) declined.

Beginning in the 1980s, the phenomenon was rediscovered independently by several researchers. First, Maylor (1985) and Posner, Choate, Vaughn, and Rafal (1985) used prior entry to measure facilitation by visible *peripheral cues* (see also Gibson & Egeth, 1994). Second, Neumann (1982; published as Neumann & Scharlau, 2006a) reasoned that prior entry may accompany *visual backward masking*: a mask—a visual stimulus that degrades or obliterates the percept of an earlier stimulus at the same location (a 'prime')—should be perceived earlier or as earlier than a like stimulus that is not preceded by a prime (see also Bachmann, 1989). Third, the phenomenon of illusory line-motion (ILM) has been related to prior entry: a stationary line preceded by a peripheral cue at one of its ends (or attended to at one end) seems to develop from the attended end (e.g., Hikosaka, Miyauchi, & Shimojo, 1993). Attention speeds up processing of the line, and it does so the more, the closer a part of the line is to the current focus of attention. This graded speed-up induces the percept of motion within the line.

In addition to these studies, prior entry has been recently used as a means to investigate attentional processing in visual extinction and neglect (e.g., Baylis, Simon, Baylis, & Rorden, 2002; Karnath, Zimmer, & Lewald, 2002; Rorden, Mattingley, Karnath, & Driver, 1997). Herdman, Stelmach, and coworkers used prior entry to study the relationship between eye movements and attention and to answer the question how attention sharpens the profile of neural codes in the visual system (Stelmach, Campsall, & Herdman, 1997; Stelmach & Herdman, 1991; Stelmach, Herdman, & McNeil, 1994). Further, Shore, Spence, and Klein (2001) explored whether the potential prior-entry effect results from a judgment bias and found a substantial bias when the

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orienting of attention was induced by instruction. The same bias was present in an experiment with visible cues, but here, the purely attentional effect was much larger.

In the present paper, the interest in prior entry is tied in with the second rediscovery: In visual backward masking, the mask's latency is shortened. This phenomenon has been termed perceptual latency priming (PLP). Although prior entry has a long history, research on PLP is very recent. In the following, I provide a synopsis of the latter. I will first summarise the features of PLP. Second, I will outline doubts about the attentional origin of PLP and how they have been addressed in experimental research. Finally, I introduce three possible explanations of PLP and compare them to the empirical evidence.

Empirical findings

Perceptual latency priming can be most easily measured by temporal-order judgments: two visual stimuli are presented with a short onset asynchrony and the observer has to judge which of them comes first. In the experimental trials, a prime precedes one of the to-be-compared stimuli. The primed stimulus then seems to lead the unprimed stimulus when they are presented simultaneously and even if it trails the unprimed stimulus by a short interval. Besides temporal-order judgments, illusory line-motion can be used to assess PLP (Scharlau & Horstmann, 2006). Also, if observers tap in synchrony with a visual stimulus, a masked prime preceding the tapping stimulus leads to an asynchrony: the taps are predated (Aschersleben, 1999a, b).

The time course of PLP

If PLP has an attentional basis, the temporal variable determining its size should be the interval between the onset of the prime and the onset of the primed target (priming interval). The attentional explanation assumes that the prime triggers a shift of attention towards its location. This cuts down on processing time of the primed mask because attention-related processing can begin immediately upon its presentation or, at least, earlier compared to a situation without a prime. This "head-start" of the mask should be the larger, the more time there is to shift attention. Yet, it cannot exceed the duration of an attention shift. That is, up to the time needed for a shift of attention, PLP should roughly equal the size of the priming interval. The maximum of PLP should equal the duration of the attention shift.

In different judgment paradigms, the duration of attention shifts was estimated at 100–200 ms (e.g., Nakayama & Mackeben, 1989; Suzuki & Cavanagh, 1997). The peak of PLP falls between 100 and 300 ms which accords with these estimates. Below the peak, PLP increases linearly with priming interval; beyond it, it slowly decreases. However, slight PLP is measurable even after up to 1,000 ms (Scharlau, Ansorge, & Horstmann, 2006). Whereas these findings agree well with an attentional explanation of PLP, the relative size of PLP deviates from the predictions mentioned above: even below its maximum, perceptual latency never benefits from the full priming interval. Its amount is only about 50–80% (Scharlau et al., 2006) or 30% (Aschersleben, 1999a) of the priming interval.

Part of this reduction results from spatial competition: in order to measure PLP, the perceived onset of the primed stimulus is compared to that of an unprimed reference stimulus. This reference may capture attention away from the prime. Indeed, PLP is larger when the reference stimulus is late in the display and thus cannot compete for attentional capture with the prime (Scharlau et al., 2006). Competition may also explain the small PLP values and the early peak of PLP reported in two earlier studies (Scharlau, 2002; Scharlau & Neumann, 2003b). In general, stimulus conditions with low competition by the reference provide the more exhaustive estimate of PLP and should be preferred. However, even when competition by the reference stimulus is abolished, PLP differs clearly from the full priming SOA (Aschersleben, 1999a; Scharlau et al., 2006). Such a reduction would be explained if attentional allocation—or other processes relevant for PLP—would not immediately begin with presentation of the prime but would need some time to accumulate. An explanation which includes such a possibility—perceptual retouch—will be discussed below.

Note also that if a temporal context is lacking—that is, if the reference and the mask are presented concomitantly—PLP may disappear (Neumann, Esselmann, & Klotz, 1993; Steglich & Neumann, 2000).

The SOA function is the main evidence in favour of the attentional explanation of PLP. As an additional source of evidence, PLP is very similar to ILM which is also assumed to be mediated by visuo-spatial attention: Attentional facilitation as measured by temporal-order perception and illusory line-motion is very similar in size and spatial properties (Scharlau, 2004b; Scharlau & Horstmann, 2006).

Spatial characteristics of PLP

Basically, PLP is related to spatial mechanisms. If the prime is equally distant from mask and reference, no PLP can be achieved. What is more, there is no sign of object-based or feature-based facilitation under these spatial conditions: PLP is neither mediated by object-based attention, nor by perceptual priming (Scharlau, 2004d).

One important question concerning the spatial distribution of PLP is whether there is evidence for a gradient of attention, comparable to the supposed attentional gradients in the closely related phenomenon of ILM (Hikosaka et al., 1993). Line-motion judgments and temporal-order judgments apparently measure the same latency facilitation (Scharlau et al., 2006). However, there is no unequivocal evidence for gradients in PLP. Its spatial distribution depends on the duration of the displays. If the stimuli continue to be presented until the judgment, PLP is both graded and spatially confined, vanishing within 2.5–5° of visual angle. By contrast, if the stimuli are transient, PLP depends less on the distance between prime and primed target, and it is even larger than in the former case (Scharlau, 2004d; Scharlau et al., 2006). We further found that latency facilitation can occur at two non-contiguous locations (Scharlau, 2004c).

At present, any interpretation of the spatial characteristics of PLP is speculative. Most importantly, the role of stimulus duration for the spatial distribution of PLP should be confirmed and explored more closely. The finding of a large focus combined with strong facilitation and a smaller focus with smaller and graded facilitation should be investigated within the context of a focusing model of attention (Shepherd & Müller, 1989). In any case, the data call for flexible mechanisms of attention control which can be adjusted to the current task demands.

Top-down control of attention

There is considerable evidence that nonconscious information guides motor responses in accordance with the current intentions (e.g., Ansorge, 2004; Kunde, Kiesel, & Hoffmann, 2003). Whether this is also true for the control of attention is less clear. Visible peripheral cues capture attention only to the extent that they match the current intentions of the observer (*contingent capture*: e.g., Ansorge & Heumann, 2003; Ansorge, Horstmann, & Carbone, 2005; Folk, Remington, & Johnston, 1992). In the PLP paradigm, we found evidence for a like top-down control mechanism, that is, contingent capture by masked information. PLP was larger if the prime resembled the target set than when it resembled a distractor set (Scharlau & Ansorge, 2003). That is, attention is captured more readily by masked information that concords with the current intentions than by information that does not match the observer's set.

Possible other sources of latency facilitation

So far, I have tacitly assumed that PLP is exclusively attentional in origin. Albeit I have provided some support for this assumption—for instance the time course which matches data from independent attention research—alternative explanations are conceivable. In the following, I will outline several alternative accounts of PLP and discuss whether they have proven to be of value.

Perceptual priming

In PLP studies, the prime is usually a downscaled version of the mask. This permits sensory or perceptual facilitation of the mask's processing by that of the prime (e.g., Wiggs & Martin, 1998). If such facilitation contributed to PLP, it should be larger when the prime and the primed target are similar. We tested this by varying shape and colour of the prime so that each feature was either similar or dissimilar to the primed target. PLP was completely independent of similarity (Scharlau & Neumann, 2003a). This finding has often been replicated (Scharlau, 2002, 2004a; Scharlau & Ansorge, 2003). Note that it does not disagree with the above finding that target-like primes elicit more PLP than distractor-like primes. The present studies on similarity compared primes which matched the target set to a greater or lesser extent because all of them had the target feature of sudden onset plus a similar or dissimilar colour or shape, whereas the studies on contingent capture compared primes which perfectly matched the target set to primes which did not correspond to the target features (here, sudden onset was both a distractor and a target feature and colour alone sufficed to distinguish a target-like from a non-intended stimulus). The experiments on similarity further revealed that PLP is independent of the prime's visibility within the range of very low to reliable detection. That is, perceptual priming is not a main mechanism of PLP. (Of course, this finding does not exclude the possibility of specific priming mechanisms in other measures of facilitation or other tasks. It would be an important task to identify the conditions under which each of these mechanisms is involved in processing.)

As a variant of the perceptual-priming account, the prime may increase the mask's perceptual contrast which may in turn decrease the perceptual latency of the mask (see, e.g., Bachmann, 1989). This alternative explanation remains to be tested in the PLP paradigm.

Sensorimotor priming

Similar to the effect of priming on choice responses (e.g., Klotz & Neumann, 1999), the prime in PLP studies could exert its influence by activating or eliciting the judgment instead of pre-dating the percept (direct parameter specification or sensorimotor priming; Neumann, 1990). In this case, an explanation of PLP via a reduction of perceptual latency would be unnecessary. This argument can be tested by comparing primes which signal the same judgment as the primed target (congruent condition) with primes which signal the opposite judgment (incongruent). If the prime eventually elicits the judgment (or the response by which the judgment is indicated), there should be more errors in the incongruent than in the congruent condition (e.g., Klotz & Neumann, 1999). However, congruent and incongruent primes have exactly the same effects on perceptual latency (Scharlau, 2004a; Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003a). This finding excludes sensorimotor priming as an explanation of PLP.

Response bias

Primes may exert their effects on a post-perceptive stage, such that the presence of the prime biases the observer towards judging the primed target as the first one—independent of whether it is actually perceived as the first one. That is, observers reporting whether a left or right target appears first while attention is directed either rightwards or leftwards might more easily judge "right" when attention is directed to the right side and vice versa. This bias might occur with any judgment criterion (Pashler, 1998).

In direct contrast to the bias argument, the judgment criterion is not essential for the alleged latency effect. For example, it does not matter whether the observers report the first or the last stimulus: PLP is the same (Scharlau, 2004a). Unmasked cues foster a slight bias (Shore et al., 2001), but masked primes do not (Scharlau, 2004a). Also, a bias should be the more effective, the better the prime can be detected. As mentioned above, PLP is independent of prime visibility.

Amalgamation

Prime and primed target are presented in close temporal and spatial proximity and may thus be confused or amalgamated. According to the P-centre hypothesis (Scott, 1998), for instance, the perceived onset of an event can differ largely from its actual onset because it is influenced by the whole temporal profile. As Jaśkowski (1991, 1993) has shown, temporal-order judgments with visual stimuli are prone to such influences.

Explaining PLP by P-centres would entail that the prime, by virtue of its earlier beginning, pre-dates the perceived onset of the mask. The P-centre hypothesis also predicts that the duration of the targets influences perceived temporal order because the onset of a short stimulus should be perceived as earlier than that of a long stimulus. Also, the temporal order of prime and mask should not matter: a leading prime should pre-date the onset of the mask, a trailing prime should shift it in the opposite direction.

As opposed to the P-centre hypothesis, the duration of the targets has no systematic influence on PLP (Scharlau & Neumann, 2003b). Comparing the effects of leading and trailing primes revealed a dissociation: both primes influenced perceived onsets. However, the effects of trailing primes were invariably smaller and less dependent on the priming interval. In contrast to leading primes, they required that the prime was visible, and they were larger under dual-task than under single-task conditions (Scharlau, 2002). This pattern of results warrants the conclusion that the latency effects of leading and trailing primes rest on different functional bases.[1]

Less specifically, PLP may be attributed to an imperfect temporal resolution of the visual system, based on the assumption that prime and primed target are perceived as a single event instead of a sequence (Pashler, 1998). Thus, the prime's and the target's perceived onset should be the same, and both onsets would be misperceived. However, empirical evidence does not support this prediction. First, the prime's onset is not misperceived (Aschersleben, 1999a). Second and as discussed above, PLP can be found with intervals of more than 100, even up to almost 1,000 ms (Scharlau et al., 2006). That is, PLP is present even when prime and primed target are clearly perceived as a sequence.

As reported above, attention-mediated facilitation is very similar in TOJs of two visual stimuli and judgments of motion within a line which connects these two stimuli (ILM; Scharlau, 2004b; Scharlau & Horstmann, 2006). This finding backups the claim that onset confusion cannot account for the PLP results: although onsets are highly relevant for the TOJ, they play no—or only a very minor—role in ILM judgments.

Besides being interesting in itself, PLP may also contribute to our understanding of sensorimotor priming, that is, response facilitation or inhibition by masked primes. In several studies, attention as well as response priming may account for the effects of the masked primes (as underlined, for instance, by Ansorge, 2004; Ansorge & Neumann, 2005). However, reaction times and temporal-order judgments as measures of perceptual latency often show a dissociation (for a summary, see Jaśkowski, 1999; Neumann, 1982).

Models of PLP

Asynchronous updating model (AUM)

Perceptual latency priming was originally predicted as a necessary by-product of visual backward masking (Neumann, 1978, 1982; published as Neumann & Scharlau, 2006a, b). This model distinguishes two main levels on which visual information is processed—*spatial map* and *internal model*. The main principle of explanation is different speed of processing on the two levels or *asynchronous updating*.

The preattentive spatial map comprises visual processes in which features of objects and proto-objects are processed in parallel in a spatially organised manner. Processing in the spatial map is fast and efficient. Par-

[1] Independent of this finding, attention may be linked to perceived duration. For instance, attented stimuli may be perceived as longer than unattended stimuli (e.g., Enns, Brehaut, & Shore, 1999; Grondin & Rammsayer, 2003; Tse, Intriligator, Rivest, & Cavanagh, 2004).

ticularly, it quickly reflects changes in stimulation. The information can be used for directly controlling motor responses (Neumann, 1990), but it is not consciously perceived.

The internal model comprises more integrated information on objects, scenes and events. Its contents are available for conscious perception. As opposed to the spatial map, the internal model is highly selective and more durable. Only information which has been attended to can be transferred to it. Furthermore, actualisation of the internal model is slow as compared to updating of the spatial map.

In backward masking, the onset of the prime elicits an attention shift towards its location and, in parallel, coding of the prime's features in the spatial map. The trailing mask also elicits spatial coding which overwrites the features of the prime. However, it does not have to start a shift of attention, because attention is already directed to its location (or on the way). Therefore, the mask's features instead of those of the prime are attended to, transferred into the internal model, and can be consciously perceived.[2]

Perceptual latency priming arises because the mask benefits from the prime having already directed attention towards its location—independent of whether attention is completely shifted or still on the way. Compared to a like stimulus which has to initiate the shift by itself, the mask can be registered in the internal model more quickly. This early registration is equivalent to a reduction of perceptual latency.

The AUM also specifies some features of PLP. For example, it should not matter for PLP whether the prime is masked or not, because the shift of attention is triggered before the prime is masked. PLP should depend on the priming SOA, rising linearly with priming SOA up to its maximum which should be equivalent to the duration of an attention shift. Below its maximum, PLP should in principle be roughly equivalent to the priming SOA. Other temporal variables, for example prime and mask duration should not influence PLP. Latency facilitation should further be a mere acceleration of the mask's perceived onset. That is, no influences on discrimination accuracy are expected, and the prime's temporal position—if unmasked—should be perceived correctly.

Perceptual retouch (PR)

Similar to the AUM, the model of PR originally addressed visual backward masking (Bachmann, 1984, 1994) and has later been expanded to illusions in the perception of dynamic stimuli (e.g., Bachmann, 1997; Bachmann, Luiga, Põder, & Kalev, 2003). Likewise, it draws mainly on a processing asynchrony. In PR, this asynchrony arises between fast *specific processing* of stimulus information in the cortex and slower *non-specific activation* via retino-thalamic and thalamo-cortical pathways. The former processes provide the contents of perceptual experience whereas the latter has a modulatory influence on specific processing. This modulation, termed *perceptual retouch*, is a necessary precondition for conscious perception.

Importantly, non-specific processing is about 50–80 ms slower than specific processing (although under circumstances not yet specified it may take more than 80 ms; see Bachmann & Sikka, 2005). Again, this asynchrony can explain backward masking: When the non-specific activation triggered by the prime reaches the cortex, the prime's and the mask's specific codes have different strengths which determine how easily and quickly each of them is retouched into a conscious percept. If the priming SOA is small, the prime's code is roughly equivalent to that of the mask so that both of them are retouched. If it is very large, each stimulus is retouched separately at different points in time. If it is intermediate, only the mask will be upgraded because the prime's codes have decayed whereas those of the mask are optimally activated.

The explanation of PLP is also very similar to the AUM: the mask is upgraded by non-specific activity which was originally elicited by the prime. This upgrading is equivalent to the emergence of perceptual awareness which is thus sped up—occurs earlier—for a primed than for a like, but unprimed stimulus.

The PR model also entails specific predictions concerning PLP. For instance, PLP should be independent of the prime's visibility (while possible in the presence of total masking). Again, the priming interval is the crucial temporal variable. The maximum of PLP should be determined by the asynchrony of specific and non-specific processing, that is 50–80 ms. PLP should thus be largest at 50–80 ms priming interval. Second, PLP should not rise above these values. Further, because non-specific modulation does not begin immediately with the presentation of the prime, the amount of PLP should be clearly smaller than the priming SOA. Also, due to the poor spatial resolution of neurons in the thalamus (Crick, 1984; Scheibel & Scheibel, 1970), PLP should be rather independent of the distance between prime and target. Because nonspecific activation is not restricted to a single sensory modality, intermodal facilitation should be possible. Further, PR arises from a spontaneous interplay of bottom-up mechanisms. Top-down control has so far not been part of the model although it might be possible (Llinas, 2001). That is, at least so far as the current version of PR is concerned, no intention-mediated control of PLP is to be expected. Note also that the PR model is able to explain latency facilitation in situations in which attention is pre-focused on a certain location (see, e.g., Bachmann, 1989) which is outside the scope of the AUM.

[2]More accurately, this asynchrony explains why masking becomes progressively weaker as the onset interval between prime and mask increases. Metacontrast masking is, however, marked by an increase of masking up to the maximum and thereafter a decrease. The initial increase can be explained by brightness summation (Neumann, 1982; Reeves, 1982).

Object substitution (OS) theory

Object substitution theory has recently been developed in order to explain different types of visual masking (Di Lollo, Enns, & Rensink, 2000). It relies on the notion of feedback or reentry within the visual system. Initially, the processing of simple features of the prime quickly proceeds in a feedforward wave through the visual system. On later stages, hypotheses about stimulus input are formed. In feedback or reentrant processing, the hypotheses are compared to the actual input in the early layers. If a mismatch between hypothesis and current input is detected, masking may arise. It occurs if the initial input (the prime) is replaced by the mask before the iterative loops between the pattern level (the hypothesis) and the early feature-level have continued for enough reentrant cycles to lead to a stable interpretation. That is, processing begins with an emerging percept of the prime, but this is replaced by the percept of the mask.[3]

The model of OS does not make predictions about whether the mask's perceptual latency is shortened by the prime. Note, however, that this is an interesting theoretical question, because in order to answer it, the model has to specify the level on which the replacement takes place. So far, there are two main proposals. Lleras and Moore (2003) suggest that an object token or object file is *updated*. These object tokens are short-lived, integrated representations of a stimulus. In masking, prime and mask belong to the same object token, and the features of the mask dominate those of the prime. By contrast, Jiang and Chun (2001) propose that the initial object file of the prime is abandoned and *replaced* by a new object file for the mask.

Object tokens cover information about features, location and time (Chun, 1997). Thus, because the time information of the prime persists in the token, the hypothesis of Lleras and Moore (2003) allows to predict that the perceived onset of the mask is equivalent to the prior onset of the prime. Contrary to this, Jiang and Chun (2001) should not expect a temporal misperception because the mask has an independent object file. In other words, if OS occurs within an object file, there should be prior entry or PLP, but if it consists in the replacement of an object file by another, no prior entry is expected.

Assuming that the perceptual history of an object begins with its entry into the reentrant process (not with the success of reentrant hypothesis testing), we can derive some few predictions about PLP. For instance, PLP should be related to the priming SOA. It should increase with priming SOA as long as the SOA does not suffice to complete the reentrant process and establish a separate object file for the prime. So far, there are no authoritative quantitative estimates on the duration of reentrant cycles. Activity in V1 is particularly prone to feedback influence at 80–150 ms poststimulus (Lamme & Roelfsema, 2000). It is, however, unclear whether this first sign of a cycle is equivalent to the typical reentry duration. Speculatively, object substitution predicts a fairly late peak of PLP, at least later than 100 ms.

Perceptual latency priming should also depend on prime visibility. A visible prime should prompt a separate object file so that no influence on the mask's object file is expected. Further, the OS model should assume that the spatial selectivity of PLP is variable, depending on the spatial resolution of the visual processing area that provides the hypothesis.[4]

[3] In the current context, this is the most important process in visual masking within object substitution. Besides, the OS model also allows for, e.g., local contour inhibition (Enns, 2004).

Closing comparison of the models

In the remaining part of the paper I will cautiously attempt at a comparison as to which of the models best explains the pattern of PLP. I will proceed by recalling the main features of PLP one by one and afterwards shortly listing the main shortcomings of each model.

- PLP is independent of prime visibility. This finding fits well with AUM and PR whereas OS should predict no PLP by visible primes.
- Up to intervals of about 100–300 ms, where it peaks, PLP depends linearly on priming interval. These findings are concordant with the AUM. The maximum of facilitation is clearly later than 80 ms which contradicts the PR model (unless it is shown that, under certain circumstances, PR maximisation may take more than 80 ms). However, the latter can explain that PLP is invariably smaller than the priming SOA, even under optimal conditions. The model of OS does not make a testable prediction about the duration of reentry so that the findings neither backup nor weaken it.
- Similarity of prime and mask is irrelevant for PLP. This agrees with AUM and PR, but only partly with OS.
- PLP depends on spatial mechanisms and has flexible spatial properties. It can occur at two split foci, within small areas of about 2.5° of visual angle but also cover much larger areas. That is, the responsible mechanism seems to be able to operate with the precision of about 2° of visual angle. This pattern agrees best with the OS model which should allow for varying spatial resolution depending on which visual area gives rise to the hypothesis: in general, higher visual areas come along with lower spatial precision. Some parts of the findings, most notably split foci, also agree with the

[4] A further explanation of PLP may be provided by the temporal-profile model (Stelmach & Herdman, 1991). It assumes that the processing of attended stimuli is accelerated. As a consequence, the temporal profile of the activity pattern of the stimulus sharpens. This model is fitted to prior entry with endogenous control of attention and not specific enough for the priming paradigm. For instance, it does not allow for predictions about time course or spatial resolution of PLP.

AUM. The PR model predicts a low spatial resolution of non-specific activation. Note, however, that none of the models can cope with the finding that the spatial resolution of PLP depends on prime duration.

- Finally, PLP is open to top-down control. This is not compatible with the current version of PR. The AUM neither negates nor affirms the possibility of intention-mediated control. However, the notion of direct specification of responses by spatial-map information is related to it (Neumann, 1990). The concept of reentry has recently been connected with intention-mediated control on pre-attentive processing (Di Lollo, Kawahara, Zuvic, & Visser, 2001) so that an integration seems possible.

To summarise, the AUM is consistent with most of the findings, except for the so far unexplained influence of prime duration on the spatial precision of PLP, the variable spatial precision of PLP and the fact that PLP is considerably smaller than the priming SOA, even when competition between prime and reference cannot account for the reduced size.

The present version of the PR model has difficulties in explaining the temporal properties of PLP, in particular its late peak. Further, PLP can be spatially much more precise than the assumed process of retouch. Especially the possibility of split foci contradicts the notion of PR.

The OS account cannot easily explain why PLP is independent of prime visibility and prime-target similarity. As to the temporal properties, its current form does not allow for testable predictions. Albeit the model is in accordance with a vague notion of spatial flexibility, at present it cannot be deduced in which cases PLP is spatially precise and under which conditions it is not. However, the main weakness of OS is that there is no authoritative statement about the level at which substitution occurs so that all the possible explanations remain speculative.

Feedforward or reentrant?

The AUM, which does a fairly good job in explaining PLP, originally was a feedforward model, and the idea of feedforward facilitation (earlier entry into the internal model) suffices to account for PLP as well as the different properties of PLP. Yet, reentrant interpretations of asynchronous updating are possible (Carbone, 2006), and an integration of reentrant processing may be a promising perspective for further development of the AUM. As delineated above, the notion of object-token updating even provides a general framework in which PLP could be explained via feedback processes. A cautious implication of the present work thus is that there is at present no need for a reentrant explanation of PLP.

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