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Looming perception: seeing in a dynamic world

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Abstract: Typically, just a few seconds before being hit, one experiences a relatively primitive sense of impending collision, something like “This is going to crash into me!”. Here I propose to explain the sense of impending collision in terms of amodal completion. Thanks to it, one can be visually aware of more than what one can actually see and I shall argue that this can be true not only for objects but also for dynamic events. But what mechanisms are involved in amodal completion? Do they qualify as perceptual or should we rather conceive them as being imaginative? Here I propose that there is a sense in which one can be said to have a perceptual sense of the future.

Keywords:

Time-to-collision; prediction; motion perception; imagination; touch; peripersonal space; future orientation; amodal completion; looming stimulus.

Introduction
The world is presented to us as being dynamic, the spatial relationship between us and the objects that we perceive constantly changing. The task for the perceptual system is to distinguish between changes that come from the subject moving (self-motion) and changes that come from the objects moving (object motion). Once it has been determined that the object is in motion, the perceptual system then differentiates biological motion from non-biological motion. It also needs to determine whether the object is looming toward the subject or not, and if so, when it may come in contact with her, what is known in the literature as the time-to-collision (TTC). These last 40 years or so, there has been a large experimental literature on how one reacts to looming stimuli on a collision course, either testing in the field with sportsmen, car drivers and pilots, or in the laboratory using psychophysical tasks (for review see Tresilian, 1999; Gray and Regan, 2000; Yan et al., 2011). Under optimal conditions (involving binocular perception), one is extremely accurate, overestimating by no more than a few milliseconds (Gray and Regan, 1998). TTC information can then be directly exploited by the motor system to program either avoidance or interceptive responses. In addition, seeing looming objects can elicit a relatively primitive sense of impending collision, typically just a few seconds before the impact. Many times in movies (especially in 3D), video games, and virtual reality, we can have the strong impression – though mistaken – that something is going to hit us though we know perfectly well that nothing can reach us, seated in our safe living-room. We then experience something like “This is going to crash into me!” One may say that it expresses more than the mere impression that an object is currently moving towards us. It informs us about what might happen to us in the close future.

Here I shall propose that to best understand the sense of impending collision, we need to switch from an object-oriented and space-oriented conception of perception to a more dynamic event-oriented and time-oriented conception. There have been many discussions on apparent motion. In the well-known phi phenomenon, for instance, participants report an
illusory impression of movement when seeing two brief stimuli presented successively at two distinct locations (e.g., Dennett and Kinsbourne, 1992; Dainton, 2008; Grush, 2006; Hoerl, 2012). Though it bears some similarities with apparent motion, we shall see that the sense of impending collision raises its own set of questions. Indeed, unlike standard cases of motion illusion, it involves the end of the motion, instead of intermediary stages. Secondly, the temporal scale is much larger. Apparent motion works for a time lag of 100 milliseconds between the successive stimuli, whereas the TTC is of a few seconds in most experiments. Thirdly, the sense of impending collision does not consist in an illusory visual experience. As I shall propose, it results from amodal completion, which enables one to be visually aware of more than what one can actually see. Here I shall argue that this can be true not only for objects but also for dynamic events.

I shall then explore the mechanisms involved in amodal completion. Do they qualify as perceptual or should we rather conceive them as being imaginative? Perception is factive: it is about what happens. One may thus immediately reject the proposal that one can perceive something that has not happened yet and that may never happen. By contrast, imagination is often characterized as the ability that allows representing what needs not be actual. It thus seems particularly appropriate for representing the future. One may then suggest that anticipating the collision is just running offline the rest of the on-going looming motion till its end ‘in one’s head’. There are many ways, however, this view can be spelled out and we shall see that none of them can fully account for the sense of impending collision. Instead, I will argue that there is evidence that points towards a perceptual account. If this is right, then it means that there is a sense in which one can be said to have a perceptual sense of the future.

1. A future-directed awareness
Compare the following two scenarios.

(a) You see a ball coming towards you from the other side of the field.

(b) You see a ball 1 meter away coming towards you.

In both cases, the direction of the ball motion is exactly the same: you experience that the ball is moving and you also experience that it is moving towards you. Thus, in both cases, you have a dynamic egocentric experience: you locate the object in motion in its spatial relation to you. Still, there seems to be a phenomenological difference between (a) and (b). It cannot be only because of a sense of danger. Arguably, cricket players do not feel afraid each time they play and they see a ball approaching them. Instead, I suggest that it is because you experience a sense of impending collision only in (b). Roughly speaking, you experience that the ball will crash into you any second now. This goes beyond the basic awareness of the on-going looming motion because it has a future orientation. True, the collision will happen very soon but still, it is not now. If it were not future-oriented, the sense of impending collision would be relatively useless because one needs to anticipate the event before it might occur to have the time to be ready. Future orientation is crucial for action planning. Behavioral responses to a risk of collision are not mere reflexes. Though often automatic, they are still flexible, depending on a variety of parameters that determine the type of response (avoidance or interception) and the way to execute it (with the hand or a tool like a racket). We have now known for a long time that action is essentially predictive (Wolpert and Flanagan, 2001) but it is even more so for looming stimuli. When the object that is the target of an action is simply in motion, as in the game of duck hunter in attraction parks, one needs to visually predict where it will be in the soon future in order to plan the right motor command, such as shooting it. Visual prediction then follows from one’s intention to act. When the object is looming towards the subject, visual prediction must come even before the intention is generated. The anticipation of the impact explains that one start moving, instead of staying still.
Future orientation, however, is not only a sensorimotor problem of logistics. One needs to ascribe a future location to the event to be motivated to act on it. If one were aware of the future collision as happening now, then it would deprive its motivational force from the sense of impending collision. By representing the collision as located in the future, one is aware that it is still open whether there will be a collision or not. This may not be the case from a metaphysical perspective, but from our epistemological perspective, we do not know whether the event will happen or not, and thus we feel that we can still do something about it. Roughly speaking, the die has not been cast yet and the future still seems up to us. As noted by Debus (2014, 2017) about future-directed mental time travel, it exhibits “agential openness”: 

Agential openness claim: when a subject S-imagines a future event, the subject is aware that she herself, or others, might act in ways that could bring about, or prevent, the actual onset of the very event that she S-imagines now. (Debus, 2016, p. 232) 

Thanks to the sense of impending collision, we are aware that we can act in ways that could prevent the occurrence of the very event that we anticipate. The role of the sense of impending collision is not for the control of fine-grained visuomotor action. TTC information can be directly exploited by the motor system without one being aware of it. The role of the sense of impending collision is rather at the executive level. It can guide the allocation of attention and the selection of actions. In brief, the sense of impending collision can justify why we abruptly drop everything we were doing in order to duck. Most philosophical interest has focused on the motivational role of pain for bodily protection, but pain strikes when it is too late: something wrong has already happened. The sense of impending collision aims at preventing the pain to even occur, and for that it needs to have a future orientation. I shall

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1 This does not entail that there is a feeling of future-ness associated with the awareness of the collision (for discussion, see Fernandez, 2020; Debus, 2016).
now propose that it is thanks to the mechanism of *amodal completion* that we can be aware of what has not (yet) happened.

2. A temporal version of amodal completion

Perceptual completion is typically defined as the filling-in of the missing features of a stimulus that is physically present. One can distinguish two types of completion, which obey different laws (Singh, 2004).

![Figure](https://via.placeholder.com/150)

**Figure** – (a) Modal completion  (b) Amodal completion

In *modal* completion, one experiences a sensory impression in the absence of corresponding sensory signals. For example, you have an illusory visual experience of a bright white square, defined by a sharp illusory contour, occluding four black Pac-man shapes (see Figure 1a). Unlike modal completion, *amodal* completion does not involve phenomenal filling-in. One perceives the completeness of the object but without having the impression of actually seeing the missing parts. In the shown example, it looks to you that there is a full black square partly occluded by a grey circle (see Figure 1b). Thanks to amodal completion, you are aware of the square as a whole, and not of some parts of it only. Nonetheless, what it is like to see the
occluded parts of the square is not the same as what it is like to see its visible parts. It is in this sense that it qualifies as being a-modal.

As most of the literature on perception, the phenomenon of perceptual completion has been studied mainly in static scenes. It has been described for shapes and objects perception but a similar phenomenon can occur for dynamic events such as motion (Burge, 2010; Viera and Nanay, 2020). For example, if you see two photographs depicting a simple movement, the two photographs differing only in the position of one limb segment relative to a joint, their rapid alternation gives rise to an apparent motion percept, which represents the shortest possible path for the limb. Execution of a limb movement along this seen trajectory is, however, not anatomically possible, as it would violate natural joint constraints. When the presentation rate slows down, participants perceive paths of apparent limb movement that follow natural human limb trajectories (Shiffrar and Freyd, 1990). One way to interpret this result is that the intermediary stages of the biological motion that are not visible are represented thanks to kinesthetic knowledge about possible movements provided ample processing time. Put it another way, the biological motion is completed. Another example of motion completion can be found in the cutaneous rabbit illusion (Geldard and Sherrick, 1972). Repeated rapid tactile stimulations at the wrist, then near the elbow, can create the illusion of touches at intervening locations along the arm, as if a rabbit were hopping along it. There is a tactile filling-in mechanism for the intermediary motion stages, though they have never happened. One may then say that both examples involve modal completion: one has an illusory visual or tactile experience of motion.

The sense of impending collision is another example of motion completion, though as mentioned in the introduction, it differs on several respects from standard cases of motion illusion. Most importantly, as I shall now argue, it results from amodal completion. Consider what happens in most TTC studies. The experimenter artificially generates the impression that
a sphere is moving toward the participants at constant speed. Then the sphere becomes no longer visible. Participants are then asked whether it will arrive before or after another looming sphere presented in the same manner (Field and Wann, 2005; Yan et al., 2011) or an auditory stimulus (Gray and Regan, 1998). For them to do so, they need to ‘complete’ the end of the motion. This does not entail that they have a visual experience of the forthcoming collision. In classic cases of amodal completion, one does not visually experience the occluded part of the object in the same way as when the part is not occluded. Likewise, what it is like to experience the collision when one anticipates it is not the same as when the collision really happens. Consider Chemero’s (2009) detailed description of a video game simulation of a car collision:

1. As your car approaches the wall, the image of the wall on your monitor expands.
2. When you get close enough, individual bricks will become visible.
3. As you continue toward your virtual crash, the image of the wall will cover the entire monitor, and images of individual bricks will expand.
4. As you get closer to the wall, the images of the bricks will expand so that only a few of them are actually able to fit on the monitor, and they will appear textured.
5. Moving closer still, the images of the texture elements on the bricks will expand as well;
6. Then there is the loud crash noise and the cracked virtual windshield. (Chemero, 2009, 123-124)

When we simply anticipate the collision, we clearly do not experience something like that. We do not experience the looming object filling more and more our visual field the closer the object gets, until it occupies most of our visual field and appears all blurred (if it is in a
direction path toward our eyes). There is only an amodal filling-in of the motion when anticipating contact. What, then, do we experience when we have a sense of impending collision?

When one sees an object partially hidden from sight, the object still looks complete. One may then say that one is visually aware of the *whole object* even if one does not see some of its *spatial parts*. Now, when one sees a looming object on a collision course, I argue, one can be visually aware of the *whole event* even if one does not see some of its *temporal parts*. Thanks to amodal completion, one is aware of more than the temporal part of the event that one is currently seeing; one is aware of the unfolding of the whole event until its natural conclusion (meaning its collision).\(^2\) The sense of impending collision consists in this awareness. It is not just the current motion; it is not just its future ending; it is whole of it, how what is happening now will continue happening until it eventually stops.

Now one may worry that unlike most examples of perceptual completion (including apparent motion), the part to complete is the end of the event, and not some intermediary stage. However, there is evidence that the perceptual system can extrapolate on-going motion, as illustrated by the phenomenon of representational momentum. It has been found that when one has to indicate the remembered final location of a moving target, it is usually displaced from the actual final location in the direction of anticipated motion (i.e., the target is judged as traveling slightly farther than it actually travelled) (Freyd and Finke, 1984; Hubbard, 2010). This indicates that one does not simply represent the motion with a certain direction; one can represent the next step, which has not happened yet and which may never happen. Motion extrapolation can be used to compensate neural processing times: the stimulus keeps moving after the sensation was initiated but before that sensation reaches perceptual awareness, and

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\(^2\) By natural conclusion, I mean the conclusion that would normally be reached if nothing happens that prevents it.
thus without extrapolation, the visual experience would always lag behind the actual position of that target (Nijhawan, 1994). Motion extrapolation, I propose, can also be used for computing TTC. It is important to understand though the completion is about the future, it is not about a new event. It is only the hidden end of an occurring event. Debus (2014) claims that one cannot be experientially aware of a future particular event because we lack the right causal connection with it. However, though one has no direct informational link with the collision itself, one has a direct link with the motion of the object, to which the collision is only a potential endpoint. We do see the looming motion, we simply do not see all of it. One is only predicting the climax of a particular event already happening, an event that one is currently perceiving. Thanks to motion completion, one does not simply represent “a collision”. One represents “this collision”, which is spatially and temporally anchored in virtue of its direct spatiotemporal continuity with the current event of motion. This is what makes its timing predicable with such an accuracy.

3. Imagining the future

To propose that the sense of impending collision is made possible thanks to amodal completion, however, does not answer all the questions. One still needs to understand how amodal completion operates. Nanay (2010) considers four possible accounts: in terms of sensory inputs, in terms of perceptual belief, in terms of sensorimotor access, and in terms of mental imagery. He disqualifies the first three and argues in favor of an imaginative conception of amodal perception (see also Brown, 2018 for a similar conception). On this view, one perceives the full square despite it being partially occluded in Figure 1b because one’s visual imagery represents its occluded parts and the visual image is projected in egocentric space, that is, in the space in which one sees the visible parts of the square. Visual imagery then fills in the gap, so to speak. Likewise, Viera and Nanay (2020) claim that
motion completion involves temporal mental imagery. Mental imagery seems particularly appropriate for predicting a forthcoming event. According to Moulton and Kosslyn (2009, p. 1274), this anticipatory role is even the primary function of mental imagery:

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\text{Imagery allows us to answer ‘what if’ questions by making explicit and accessible the likely consequences of being in a specific situation or performing a specific action. For example, imagery can allow us to predict the path of a projectile.}
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But what exactly does one imagine when one predicts the path of a projectile coming towards one’s body? We shall now see that the imaginative account is open to several interpretations and that no matter how one tries to spell it out, it faces a series of difficulties.

Let us first simply assume that the sense of impending collision involves running off-line the simulation of the motion of the stimulus approaching until impact. This is what is actually asked from participants in a series of studies on TTC (Vagnoni et al., 2012, 2015, 2017, 2020). They are asked to imagine the object continuing to approach at the same rate and press a button when they judge that it will collide with them. However, there is an obvious basic problem with this interpretation. In the studies, the participants start imagining when the looming stimulus stops being visible. But in real life, one generally keeps on seeing the motion that is unfolding under one’s eyes. Why mentally running in parallel the simulation of the motion that one is actually seeing? There is no information to gain, especially since it cannot afford anticipation of what is forthcoming. Indeed, running such simulation takes time, too much time. More precisely, the time that it takes for the participants in the TTC studies to finish running their mental simulation of the motion has been found to be a reliable proxy for the time it would take for the motion to be actually completed (Vagnoni et al., 2012). Imagination is then explicit but the same dynamics should be found at the implicit level (Jeannerod, 1994). Hence, on the basis on motion simulation, one can know about the
collision only at the end, when it is supposed to occur. This cannot give rise to the sense of impending collision, which is anticipatory by nature.

One may then suggest that the sense of impending collision involves only visually imagining the collision itself, and not the motion that leads to it. But is visual imagery the best modality for that? Let us go back to our previous example of the approaching ball. When the ball is really close to you, you experience that it is going to crash right on your face. But what is it like to visually imagine the crash? If you were really hit by the ball, your visual experience would be quite limited, or even non-existent. The problem is not only that for objects to be properly seen, they must be not too close from the eyes and collision necessarily means the absence of distance between the perceiver and the object. The problem is also that one automatically closes one’s eyes, what is known as the blink reflex, which is a defensive response to threats. You thus have little past experience of seeing the ball hitting you, at least from the inside. It is only if you adopt a third-person perspective (from the outside) that you can visually represent the collision, by visualizing the ball next to your face, from the outside. Allocentric imagination, however, does not appear as the right candidate for the sense of impending collision, which can be conceived as an anticipatory form of egocentric awareness.

There is, however, an alternative imaginative account, which appeals to touch instead of vision and which can preserve the first-personal character of the sense of impending collision. On this interpretation, when one sees a looming object, one spontaneously engages in a task of tactile imagination, simulating the impact from the inside. The specificity of touch is to give access to the relational property of pressure from a first-person perspective (Vignemont and Massin, 2015), and what is collision if not a form of pressure exerted by an object against one’s own body? In favor of this view, it has been shown that merely seeing objects can trigger tactile expectations. For instance, one is slower and makes more mistakes to judge the location of tactile stimuli if at the same time one sees a visual stimulus close to the body but
at a location that is incongruent with the tactile stimulation (Spence et al., 2004). This kind of cross-modal effect can be explained by the fact that the perceptual system anticipates the potential impact of what is seen, thus generating tactile expectations, which then compete with the experience of the actual tactile stimulus. However, though this new imaginative account shows promise, it cannot be the full story for the sense of impending collision. It is only when visual stimuli enter the immediate surrounding of one’s body (up to 50 cm), what is known as peripersonal space, that tactile anticipation occurs.  

3 When the approaching stimulus has not reached this stage yet, there is no visuo-tactile effect. Imaging studies confirm that the perception of looming stimuli partly engages the network involved in the processing of peripersonal space but goes beyond it (Clery et al., 2019). Since fMRI studies have a bad temporal resolution, one can only speculate that there is first a distinct network activated by looming stimuli before the activation of the peripersonal network, which occurs at the very end of the looming.  

4 Put it another way, the tactile system waits until the last minute to kick in, or more accurately, until the last milliseconds, when the looming object is located at less than 50 cm from the body. By contrast, one starts experiencing that the ball is going to hit one’s body before. Hence, though a better candidate than visual imagining, tactile imagining cannot account for the sense of impending collision, unless one wants to restrict it to peripersonal space.

One may then propose that one is aware of the forthcoming collision not in virtue of visually or tactually imagining the object in contact with one’s body, but in virtue of motorically imagining one’s response to it. In line with this motor interpretation, it was found activity in sensorimotor areas in the dorsal pathway normally involved in reaching and catching, though the TTC task was purely perceptual, with subjects remaining perfectly still in an MRI machine and the approaching sphere being only shown on a screen (Field and

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3 For a comprehensive multidisciplinary investigation of peripersonal space, see Vignemont et al (2021).
4 Thanks to Justine Clery for her help on the relation between looming perception and peripersonal space.
Another study shows that participants underestimated more TTC if they had reduced freedom of movements (Vagnoni et al., 2017). It may then seem that motor imagery is the most appropriate form of imagination for the sense of impending collision. This would be in line with other findings on the role of motor imagery for perception. For instance, it has been found that to judge the laterality of a hand visually presented with different orientations, participants mentally rotate their own hand to match the visible hand, as shown by the fact that the larger the angle of the rotation to perform, the more time it takes to answer (Parsons, 2003).

There is a major difference, however, between the laterality task and the TTC task. Motor imagery can be used to determine whether one sees a left or a right hand, but it cannot be used to determine whether there will be a collision or when the collision will occur. It is actually the other way around: one first needs to anticipate the collision before running off-line one’s motor system. Otherwise, there would be no reason to plan one’s motor response. Nonetheless, though motor imagery is not the source of our anticipatory awareness, it can still accompany it. As said earlier, the sense of impending collision plays a motivational role and it should not come as a surprise that it can trigger the mental rehearsal of avoiding or intercepting behaviors.

At first sight, imagination seemed to be the best candidate to account for the anticipatory awareness of collision but it is actually not clear how it can account for what one experiences. As argued, motion imagination takes too much time whereas collision imagination is best imagined tactually and motorically than visually. However, tactile and motor imagination cannot ground the sense of impending collision; they can only accompany it. No matter the modality, one may further object that imagination cannot play the motivational role that is

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5 The effect of one’s bodily incapacities on TTC estimation may just be the result of a general bias of the type “allow you more time”. But the bias does not have to be the result of an off-line motor simulation. The fact is that the timing of action preparation is slightly different from TTC.
played by the sense of impending collision. The relation between imagination and action is highly debated but it seems that even if it can play some role in guidance, its relation to the motor system is not direct (Kind, 2011; O’Brien, 2005; Currie and Ravenscroft, 2002). If so, simply imagining a collision does not suffice to get one to react. Finally, the imaginative account of amodal completion is not without controversies. For Briscoe (2011; 2018), a key feature of visual imagery is its distinctive phenomenal character, which is similar to visual experiences so that one can fail to distinguish between them. Visually imagining the square involves having a visual impression of it with a specific brightness. But amodal completion precisely qualifies as amodal because there is no such visual impression. Furthermore, Briscoe (2011) claims that imagery generally fades rapidly, whereas amodal completion is relatively stable, even if you look at the partly hidden object for a long time. He also notes that though imagery does not have to be voluntary, it still normally remains under control and one can modify its content. By contrast, amodal completion is obligatory. One cannot help but being visually aware of the full of object, or of the full event in our case.

There is, however, a further interpretation of the imaginative account - one defended by Nanay (2010, 2016, 2020) and Brown (2018) - which may not run into all these difficulties. On this view, visual imagery should be clearly distinguished from visualizing. Instead, it should be conceived as a specific type of visual representation that supplements and enriches perceptual processes. Brown (2018, p. 149) concludes that there is “a seamless infusion of perception with imagination”. As a consequence, it may be difficult to take apart the respective contribution of each. Nanay (2016, p. 129), for instance, suggests the following criterion: content comes “in a bottom-up way in perception whereas it comes in a top-down way in mental imagery”. This use of the notion of mental imagery is relatively liberal and many may question the definition not only of imagination but also of perception. In a sense, what is really at stake in this debate is the boundary of perception, where it ends and where
something else (call it mental imagery if you want) starts. Depending on the answer, the sense of impending collision may be conceived as perceptual or as imaginative. Clearly, the debate on the boundary of perception goes beyond the scope of this chapter and here I will simply review the evidence that points in the direction of a perceptual interpretation of the sense of impending collision. I shall now argue that though there is no corresponding sensory stimulation for the collision, the sense of impending collision still results from a bottom-up process of motion completion that is stimulus-driven. This conception is in line with the way TTC estimates are described in the experimental literature. For many indeed, one “directly perceives” TTC (e.g., Vagnoni et al., 2012; Tresilian, 1999; Yan et al., 2011, Gray and Regan, 1999).

4. Perceiving the future?

Amodal completion has been shown to occur very early on in the visual system, in a pre-attentive manner. It is thus generally conceived as a purely perceptual bottom-up mechanism (Burge, 2010; Phillips, 2017; Kalpokas, 2017; Briscoe, 2011). Most discussions, however, have focused on object completion, and not on motion completion. Here also it involves early visual mechanisms, which have been found in many animal species and in human infants as early as 12-month-old (van der Meer et al., 2012). In the primary visual cortex, there is a specific neural mechanism that fixes the direction of the object motion in 3D space and that is preferentially sensitive to increasing or to decreasing object size, what has been called a looming detector (Regan and Beverley, 1978). It has been shown, for instance, that participants’ attention was automatically drawn toward a looming stimulus in visual search task, though it was not the target but only a distractor (Lin et al., 2008). The estimation of TTC is then generated on the basis of early visual mechanisms, which extrapolate the rest of the motion on the basis of low-level visual cues (Nijhawa et al., 1994). More specifically,
TTC can be computed using only the optical variable tau (τ), defined as the inverse of the relative rate of expansion of the incoming object’s image on the retina (Lee, 1976):

$$\tau = \frac{\theta}{(\Delta \theta / \Delta t)}$$

In which \( \theta \) represents the projected angular size of the approaching object, and \( \Delta \theta / \Delta t \) represents the rate of expansion of the image. The optical variable \( \tau \) decreases approximately linearly with time and it is as its minimum shortly before TTC. On the only basis of \( \tau \), one can predict TTC with remarkable accuracy. The optical variable, however, works only for constant suprathreshold speed rate, neglecting possible acceleration, and it does not work for very small objects or asymmetrically shaped objects (Tresilian, 1999; Yan et al., 2011). Other parameters can then contribute to TTC estimates but they remain relatively low-level visual features, such as size and distance.

Still, it is worth noting that although the estimation of TTC does not require additional knowledge to be computed, it can still be modulated by cognitive factors. A series of studies show that participants underestimated more TTC for threatening or large objects relative to non-threatening or small ones (Vagnoni et al., 2012, 2015, 2020). However, the fact that TTC judgments can be influenced by semantic information does not show that motion completion is generated by top-down mechanisms. First, it is unclear whether this modulatory effect occurs at the perceptual level or at the post-perceptual level only, as acknowledged by the authors of the studies themselves (Vagnoni et al., 2017). Secondly, TTC can be computed independently of any recognition of the looming object. In this sense, TTC involves only what Briscoe (2011, 2018) calls stimulus-driven completion, by contrast with cognitive completion. It is equivalent to the example of the occluded square previously described (Figure 1a). Its completion is based on sensory cues only and does not rely on stored knowledge. It is different from cognitive completion, which depends on categorial recognition. For instance, if
you see just the front of a horse, the rest appearing to be occluded, you can perceive the horse as a whole but only if you know what a horse normally looks like. Without one identifying what one sees, the object cannot look complete. To compute TTC does not require such top-down processing.

To recapitulate, when seeing a looming stimulus, the visual stimulation on the retina and its corresponding optical expansion reliably trigger the computation of the optical variable $\tau$, and there is no need to recognize the stimulus. Some may even conclude that we can directly pick up the information about the forthcoming collision, in Gibson’s (1979) sense:

> Note that $\tau$ need not be computed by the gannet. It is available at the retina. $\tau$, in other words, can be perceived directly (...) sensitivity to the ratio of optical angle to the expansion of optical angle is sensitivity to the timing of approaching collision. (Chemero, 2009, p. 124).

More precisely, one still needs to *extrapolate* the TTC on the basis of the available information. The sensory stimulation needs to be enriched by knowledge about physical principles governing motion. For some, this shows that motion completion is not perceptual. According to Brown (2018), for instance, there can be mental imagery even if operations are performed on incoming stimuli (a bottom-up process, thus), as long as the computation involves the use of “stored perceptual contents” that go beyond stimulus information and that enrich it. On Brown’s view, however, the contribution of mental imagery does not disqualify the sense of impending collision to be perceptual. Still, one may question this interpretation. It is true that the sense of impending collision requires knowledge about physical principles governing motion but it is not clear how this knowledge is implemented. Are physical principles governing motion the content of a dedicated representation or are they simply incorporated into the functional properties of the cognitive architecture? One may further
challenge the assumption that all internal models that enrich perception qualify as mental imagery. For instance, Grush’s (2004) proposes that what we have what he calls amodal environment emulators, which anticipate changes in our surrounding on the basis of our own movements and of the dynamics of the objects themselves. So far, this is compatible with the imaginative conception. On Grush’s view, however, emulators should be conceived as imagery only when they operate off-line, and not when they are exploited to interpret sensory inputs.

I shall not settle this fundamental debate on perception and imagery here. All we can conclude is that on some conceptions of perception at least, the sense of impending collision can be conceived as perceptual. It is a bottom-up process causally controlled by visual stimulation and based on perceptual invariant and it represents a particular event as completed, even though it is not yet finished. If this suffices for the sense of impending collision to qualify as perceptual, then this seems to lead us to an interesting but possibly challenging conclusion, that is, that one can be perceptually aware of the close future. More precisely, I propose that in the sense of impending collision one perceives the whole event, including not only its present parts but also its future parts. There is therefore a sense in which one can be said to perceive the future: in virtue of perceiving a whole event with a future part, one can be said to have visual awareness of the close future. This future that we anticipate is close in time, it corresponds to the first instants after what we experience as being now, but it is still beyond now.

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