What you see is what you set – the position of moving objects.

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Abstract. Human observers consequently misjudge the position of moving objects towards the direction of motion. This so called flash-lag effect is supposed to be related to very basic processes such as processing latencies in the human brain. In our study we show that this effect can be inversed by changing the task-set of the observer. A top-down change of the observers attentional set leads to a different perception of otherwise identical scenes. Cognitive theories regard the misperception of the moving object as an important feature of attention-mediated processing, because it reflects the prioritized processing of important objects.

1 Where do we see moving objects?

If human observers look at moving objects and judge their position at a specified point in time, they misjudge their positions towards the directory of motion. This effect is called flash-lag and known since 1931 [1]. Most theories agree that this effect is related to processing latency. The human visual system has a processing latency of about 80 ms [2]. We do not see the world as it is, but as it was about 80 ms ago. In a static world this would not be much of a problem, but in a dynamic world, objects can change positions during this time. If, for example, the tennis player Andy Roddick is to serve, he accelerates the ball up to 250 km/h [3]. In 80 ms, this ball travels 5.5 meters. Seeing the ball 5.5 meters displaced is no beginning for a successful return. A more up-to-date representation of the environment would enhance the chance to return the ball.

The same is true for technical systems. A football robot consequently misjudging the position of the ball with about 80 ms could only interact with very slowly moving footballs. Real-time representations of the outer world would enhance attempts to interact with the world. On the other hand, real-time processing is not possible, neither for robots nor for humans. How does the human visual system cope with a considerable slower processing speed? Attentional accounts answer: by having a clue what is important. If attention is deployed to a specified area in the visual field, objects inside this particular area are processed faster than objects outside this area [4]. According to the attentional view, the misperception of the moving object is not a bug but a feature.

But how does the visual system know what is important? One object could be important in one situation but totally useless in another situation. If observers have the difficult task to count passes between random moving basketball players, the ball and the players are very important. A moonwalking bear, crossing the scene would be very unimportant although moonwalking bears could be assumed to be important. If observers watch the same scene without a particular task, the player would be less important and the bear comparatively more important. Studies show that human observers consequently miss salient objects when busy with another task, but have no problem in detecting them without a demanding task [5]. In the following study, we will show that the relative importance of objects sets the perceived position of moving objects at a specified point in time.

We use a standard flash-lag paradigm with a moving stimulus and a static stimulus. The static stimulus is used as a time marker. Our setup looks like a clock face with a seconds hand traveling on the outer rim of the clock (see figure 1). The time marker is an inner clock hand that can be seen on four different positions, 3 o'clock, 6 o'clock, 9 o'clock and 12 o'clock. We realized three conditions in which the position of the moving object was to judge. The seconds hand was always visible and moving smoothly with 25 rpm around the clock. The inner clock hand was also moving with 25 rpm but only visible on four positions. It started at the 12 o'clock position, jumped to the 3 o'clock, the 6 o'clock, the 9 o'clock and again to the starting position.

In condition 1, the inner clock hand was only visible for 13.3 ms. The observer's task was to adjust the position of the seconds hand in a manner that it was aligned to the 3 o'clock position, the moment the inner clock hand was visible. The onset of the inner hand (the time marker) triggers the onset of the comparison task. One cannot judge the relative position of two objects when only one is visible. So the position of the moving object is relatively unimportant while it cannot be compared to the time marker. The time marker has to be attended-to first and afterwards the moving object.

In condition 2two, the task stays the same but the setup changes a bit. The inner hand is always visible and the seconds hand gets a head start of ¼ revolution. The task is to adjust the position of the moving stimulus that both objects are aligned when the inner hand catches up with the outer hand. To solve the task, one has to wait until the inner hand jumps and compare the new position of the inner hand to the actual position of the outer hand. Again, the time marker has to be attended-to first and afterwards the moving object.

In condition 3, the inner hand gets a head start of ¼ revolution. Now the seconds hand has to catch up with the inner hand. The task is to adjust the position of the seconds hand so that the inner hand jumps to the next position the moment both objects are aligned. Priority changes in this condition. The inner clock hand is unimportant until the seconds hand reaches its position. In this condition the moving object has to be attended-to first and afterwards the time marker.

2 Results

Figure 1 shows the average results of five observers (one author and four naïve observers) at Paderborn University. The seconds hand was seen as displaced in direction of motion when the inner clock hand triggered the onset of the task. The seconds hand was seen as displaced contrary to the direction of motion when the onset of the task was triggered by itself. The setup and the average results are depicted in Figure 1.

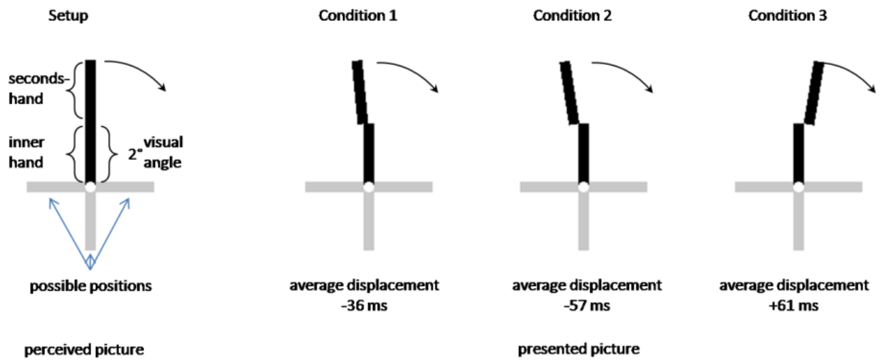

Fig. 1. In each condition the perception of the moving bars should look like the reference picture depicted under "setup". The actually presented picture did not match the subjective perceived picture. In conditions 1 and 2, the seconds hand was lagging behind the inner hand while perceived as aligned. In condition 3, the seconds hand was leading the inner hand while perceived as aligned.

These findings indicate sequential encoding of first the object that heralds the beginning of the task and second the reference object. Such a task-dependent, top-down sequence was predicted by the attentional explanation of the flash-lag effect. The point is: It is not the bottom-up properties of the presented objects which modulate the percept, but the task the observer performs.

The moving object could be seen either as leading or as lagging. Transferred to the tennis player, this would mean a more up-to-date representation of the ball if the task is returning the ball. The exact position of the opponent would be less important and could be processed later. The perception of the exact position of the tennis player has not been investigated yet. However, there are some studies on football players which are perfectly in line with our attentional explanation. If the linesman is to judge offside he has a bias towards judging offside even if there was no offside [6]. And indeed the lineman's task reminds of a flash-lag task. One has to judge the position of a moving object (the player) at a specified time (when the pass was shot). The onset of the lineman's task is triggered by the pass, so attention is first deployed to the ball and after the pass was recognized deployed to the player. Unfortunately (for the attacking team) the player has moved during this time and is being seen in an offside position after the ball was passed. Deploying attention first to the player (is he in an offside position?) and then to the ball carrier (is he passing?) should inverse the bias into less offside judgments even when the attacking player is in an offside position. Unfortunately (for the linesman) players are often in passive offside positions. In this case the linesman has to do nothing. So the strategy of first attending the player and then the ball carrier would result in much useless cognitive work.

To sum up: Our experimental results with human observers demonstrated that attention speeds up the perception of an attended object quite a bit (36 to 61 ms). Such latency effects have been reported with other tasks such as temporal-order judgments and can be regarded as a very reliable consequence of visuo-spatial attention [7, 8]. We thus can conclude that attention does not only allow for more detailed processing, object-level representations or even conscious perception, but also to faster processing [9]. As far as we know, this advantage has not yet been included in computational models of attention. An exception might be the model by Hamker [10].

We also showed that attention is top-down-mediated. It was the task, not the saliency of features which determined whether the seconds hand trailed or led the inner hand in perception. Again, this is in line with current experimental results in psychology. During the last years, an increasing amount of studies has shown that, at least in human observers, it is task-relevance, not salience, which controls attention [11, 12, 13], or that the effects of salience are at best very short-lived and replaced by top-down influences after about 200 to 300 ms [14]. According to these accounts, if salience controls attention, it does so not by default, but because salience is task-relevant in the present context. Again, this important finding has not been incorporated into computational models of attention. Although many of the current models include some top-down information, this influence is not as weighty and basic as in experimental psychology.

At first sight, attending to task-relevant objects seems to be a reasonable strategy for human observers. But what are the advantages in more detail? If processing capacity is limited, such a strategy could ensure the processing of relevant features, that is, features which are important for the current actions of tasks at hand. Another side effect of prioritization is shielding against interfering information. If for example a football robot is tracking an orange football in order to score a goal, this football has to be processed with priority. The orange t-shirt of an audience member would get less attention because it is not related to the task and although it might be equally salient) and would get less of a chance to interfere with the tracking of the football. We might also speculate that task-relevant objects very often are the objects to be acted upon – for example the object were are fixating, manipulating, tracking, grasping etc. Attention would thus serve a very important function in action control. This idea is most directly included in the premotor theory of attention [15]. In this theory covered attention shifts involve the mechanisms for saccade programming. Both, attention shifts and saccades utilize motor control circuits. All these findings an notions – attention is top-down controlled, attention is tightly coupled to the control of eye movements, attention is vital for current actions and tasks at hand – corroborate the belief that computational modeling of attention will take a major step if attention is implemented in autonomous systems.

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