Preparing to see: Neural mechanisms of top-down preparation and their influence on visual awareness of real-world objects

How do our goals and expectations influence what we perceive? When we open our eyes, one million retinal ganglion cells transmit information about light patterns on the retina at a rate of approximately one megabyte per second, roughly corresponding to the data transfer rate of an Ethernet connection. Light falling on the retina is reflected from a myriad of objects in our environment, only a fraction of which are relevant to ongoing behavior. Nevertheless, we do not suffer from constant information overload. In fact, rather than perceiving countless objects at once, only a very limited number of elements of a visual scene gain access to visual awareness at any given moment of time. The process of allocating the brain's limited processing resources to visual information that is relevant to the organism while filtering out irrelevant information is referred to as visual attention. Here, we studied how explicit expectations of upcoming relevant visual information, or content-specific attention, can influence visual awareness of objects.

First, we tested the prediction that objects have an advantage in gaining access to awareness when observers are prepared to detect the corresponding object category. For this, we used continuous flash suppression (CFS). CFS is a novel psychophysical technique in which dynamic high-contrast masks flashed into one eye render a static image projected into the other eye invisible up to several seconds. The duration of perceptual suppression under CFS represents a powerful and highly sensitive measure of the potency of visual stimuli in gaining access to awareness. To promote public awareness of research in basic vision science, we gave demonstrations of this fascinating technique at the science museum in Trento, where visitors could experience this phenomenon themselves. To measure the influence of category-specific attention on access to awareness under CFS, we presented photographs of objects from a wide range of basic-level categories under CFS and tested whether prior information about the category membership of the suppressed object (provided by a word cue) would reduce the duration of perceptual suppression. Results showed that providing participants with such prior information about the category of the to-be-detected object indeed facilitated access to awareness. Control experiments comparing valid with invalid category information ruled out that this beneficial influence of prior information reflected a non-specific effect of general alertness. Subsequent work demonstrated that similar beneficial effects of such content-specific top-down preparation could be found with psychophysical paradigms other than CFS and for visual stimuli other than photographs of familiar object categories. For example, we used oriented gratings instead of object photographs and found that prior information about the specific orientation of such gratings improved their detectability. We even found that contrast detection thresholds for faint, low-contrast gratings presented against a gray background, with no masking, were lower (i.e., better) when participants received prior information about the orientation of the upcoming to-be-detected grating. These findings provide comprehensive evidence that prior information about stimulus content improves performance in simple stimulus detection. Thus, content-specific top-down preparation can boost stimuli into awareness, and such expectation-related improvements in conscious perception represent a general phenomenon that can be observed with various tasks, presentation techniques, and stimuli.

Building up on these findings, in a second set of experiments we tested the influence of top-down expectations on the conscious perception of objects in photographs of natural scenes. The processing of natural scenes is often believed to require little attentional resources. However, for a top-down preparatory mechanism to be useful in natural vision, it should selectively enhance the processing of objects matching the relevant category even when these objects are embedded in cluttered natural scenes containing multiple objects from various

categories. Using large sets of natural scene photographs, we indeed found that prior information about superordinate categories (animals, vehicles) improved detection performance. In subsequent experiments we found that this expectation-induced advantage was independent of spatial attention, demonstrating the spatially global effect of top-down preparation for specific categories. However, detection with and without category-specific top-down preparation was impaired when observers performed an additional demanding task at fixation, showing that spatial attention alone can influence natural scene perception. These findings demonstrate that effective perception of natural scenes is facilitated by both spatial attention and category-specific top-down preparation, and support the view that attentional resources are necessary for visual awareness.

Finally, we used magnetoencephalography (MEG) to track the build-up and effect of top-down preparation in the brain with millisecond precision. For this, we took advantage of recently developed multivariate decoding analysis methods that became available for MEG only very recently. Here, we adopted a somewhat different experimental approach which was optimized for MEG decoding: Instead of employing one of our psychophysical paradigms to demonstrate effects of top-down preparation on detection, we now induced a strong top-down set through a task manipulation and tested whether bottom-up input containing no actual signal would be processed in accordance with the top-down expectation. In separate blocks, participants were asked to look for faces or houses, respectively. In the critical trials, subjects were presented with pure noise images, while looking for either faces or houses. The question was whether we would still be able to classify these noise images, in accordance with the observer's top-down set, and whether decoding for such pure noise images would differ from actual images with face- or house-signals in strength and time. Indeed, we found strong effects of top-down set: Images containing pure noise could still be categorized as faces vs. houses, depending on the observer's task, in a way very similar to images containing actual visual information about faces and houses. These findings demonstrate that top-down preparation has a strong impact on neural processing of bottom-up sensory signals, even if these contain no stimulus information at all.

The results from this project show that our goals and expectations can have a strong influence not only on what we see but can even determine whether we see something at all. Expecting specific visual information can boost stimuli matching these expectations into consciousness, and visual stimuli not containing any information are neurally processed in a way that matches the expectation. By demonstrating how the contents of consciousness are determined by top-down preparation, these findings are relevant for one of the most hotly debated topics in cognitive psychology, neuroscience, and philosophy of mind that evolves around the relationship between attention and consciousness. Our findings argue for a constructivist view, in which conscious perception is strongly influenced by our internal states, goals, attentional sets, and expectations, rather than by properties of the external world alone.