General Discussion
In daily life, there are usually many objects in sight. These objects are at different distances and some of them can be quite far away. But there are also scenes with very little visual information, like the example mentioned in the introduction of crossing a park at night, a daily life event for an Amsterdam biker. When less visual cues are available, distance judgments are less accurate (Philbeck & Loomis, 1997). We investigated how an additional object in a poor cue scene affects absolute distance judgments.

We found that when estimating the distance of an object in the dark, an additional object further away in the scene improves the distance judgment of the nearer one. In the dark, the range of distances tends to be underestimated. That is described in the introduction as the specific distance tendency. We observed that a further object in the scene reduces the extent to which the distances are underestimated. There are some theories about how relative disparity contributes to absolute distance judgments (Glennerster, Rogers & Bradshaw, 1998, Glennerster, Tcheang, Gilson, Fitzgibbon & Parker, 2006). However, only the hypothesis we suggest, the limiting factor hypothesis, can fully explain the results presented in chapter two. According to the limiting factor hypothesis, an additional further object influences the perceived distance of the nearer object by reducing the range of possible positions. Vergence, the angle between the two eyes’ lines of sight, has a geometrical limit. Looking at a very far away object corresponds with vergence zero (eye’s lines of sight are parallel). Since relative disparity is the difference between the two objects’ vergences and the furthest object vergence cannot be below zero, it constrains the range of possible positions of the nearer object. We therefore concluded that relative disparity to the further object is used as a cue for distance.

Unlike localizing the object relative to the most distant one, as is claimed by the theory that we named the anchor hypothesis (Foley, 1985, Gogel, 1972), the limiting factor hypothesis that states that the further object does not need to be exactly localized. The anchor hypothesis theory suggests that the further object is localized first and relative disparity used to estimate the nearer one’s distance. In this case, if the further object is mislocalized, the nearer object should show the same mislocalization as the further one. For testing whether this happens, we induced mislocalization for the further object location, as described in chapter three. Our data revealed that there is a systematic mismatch between the further cube mislocalization and the near cube mislocalization. This result implies that the further object is not used as an anchor and does not need to be exactly localized to contribute to the nearer one’s distance estimation. And it implies that the
subjects do not always perceive the objects at positions that are consistent with the relative disparity between them. This is in line with findings that one’s judgment of relationships in space is inconsistent with the visual space geometry (Smeets, Sousa & Brenner, 2009).

In chapter three, we induced the mislocalization by manipulating the size of the objects. When having different size cubes at the same location, subjects pointed further for a smaller cube and nearer for a bigger cube despite the objects being at the same simulated distance. This suggests that despite not knowing the real size of the cube, the subjects assumed the cube was more likely to have some sizes than others, a size prior for an unfamiliar object. They relied on retinal image size as a cue to distance to different extents, showing how large variability can be in the weight people give to different cues.

Studying the size assumptions for an unfamiliar object, chapter four, we found that when many different sizes were consecutively presented, the weight given to the size prior for an unfamiliar object as a cue to distance was halved. As found for other cues, the statistics of the environment influences how much people rely on priors (Knill, 2007). We also found, chapter five, that when many object sizes of a different colour or a different orientation were presented they would still influence how much people rely on the size prior for an unfamiliar object, but not when many object sizes of a different shape were presented. Different colour or orientation objects seem to be considered from the same category but not different shape objects.

Moreover, presenting objects with many sizes in the surrounding did not affect how much people rely on a size prior as a cue to distance. Considering previous studies on the matter (Muller, Brenner & Smeets, 2009b, Seydell et al., 2010b), it appears that when the surrounding objects are irrelevant for the task, they are not taken in consideration.

In chapter six we described how consecutively presented sizes affect distance judgments. Furthermore we found that the size of a single previous trial also affects distance judgments. We predicted that the size prior would be updated at each trial and therefore an object would be judged nearer when preceded by a smaller object because the prior would have been shifted to a smaller value. That is what we found. However, after seeing two small objects, the object should be judged as even nearer. Contrary to our prediction, the subjects do not point nearer after two preceding small objects than after one preceding small object. There seems to be instead a fast contrast effect between the retinal image sizes.

In all the experiments described (chapters 2, 3, 4, 5 and 6), size was a non-informative cue about distance.
Nevertheless size was used in distance estimation. This fact is relevant because most studies keep some cue constant and non-informative in order to isolate one particular cue (e.g. Johnston, 1991; Philbeck & Loomis, 1997; Viguier, Clément, & Trotter, 2001). However, subjects might still use the constant non-informative cues for perceptual judgments. For instance, accommodation in our experiments would point to a central default value independent of all the simulated distances because it was constant during all experiments. This can be seen in chapter one, in the results of the condition where only a sphere was presented. The only cues for distance were vergence and accommodation, and the slopes fitted to the data were shallower than in other conditions with more cues (contraction bias).

Our first five studies are not at all natural. Even though reaching for an object is a common daily task, doing that without seeing one’s hand is much less common. Also much less common is to interact with virtual objects in total darkness. However the method used, pointing at the centre of the object, seemed to be a good measure of absolute distance judgments for reachable distances in the sense that the judgments were close to veridical and in agreement with more or less cues available. Even though it is assumed that there is calibration between perception and motor control, as described in the introduction, due to subjects not seeing their hand there might have been a mismatch between the two. For instances some subjects showed systematic overestimation or underestimation of distances that could be a result of misjudging the position of their hand (Smeets, van den Dobbelsteen, de Grave, van Beers & Brenner, 2006) or a misjudgement of the target’s location. It has been described how in open loop behaviour noise can be accumulated in the sensorimotor system (Souman, Frissen, Screenivasa & Ernst, 2009). However, even with noise added, the conditions compared showed significant differences.

The study described in the sixth chapter was done in a natural environment. Usually there are many cues in natural environments and assumptions about the size of an unfamiliar object may only be used in situations where little visual information is available. We found that in a natural environment, the size of an unfamiliar object is still used as a cue for distance. In an empty beach, subjects judged a smaller red cube to be further away than a bigger red cube when positioned at the same locations. To indicate the estimated distance the subjects were asked to walk blindfolded until the position where they saw the object.

The contribution of a further object for distance estimation was only studied in a limited environment. However, it’s reasonable to assume that the further object will also contribute for distance estimation in real
environments, especially because in most scenes there are other objects present and further away than the object of which one wants to estimate the distance. The further object should also contribute for distance estimation when positioned very far away because relative disparity is still used at very large distances (Palmisano, Gillam, Govan, Allison & Harris, 2010).

In sum, we found that relative disparity to the further object is a cue for the nearer object’s distance and that objects are not always perceived in positions consistent with the relative disparity between them. Assumptions about the size of an unfamiliar object can be used as a cue for distance and people rely less on it if many sizes of similar objects are consecutively presented. Assumptions about the size of an unfamiliar size are not updated on each trial but the object’s size of the previous trials influence distance judgments, possibly due to contrast between retinal image sizes. Assumptions about size are still used in natural environments and a further object contribution for absolute distance judgments is likely to be used in daily life scenes.