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Perception of length to width relations of city squares

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Abstract. In this paper, we focus on how people perceive the aspect ratio of city squares. Earlier research has focused on distance perception but not so much on the perceived aspect ratio of the surrounding space. Furthermore, those studies have focused on "open" spaces rather than urban areas enclosed by walls, houses and filled with people, cars, etc. In two experiments, we therefore measured, using a direct and an indirect method, the perceived aspect ratio of five city squares in the historic city center of Delft, the Netherlands. We also evaluated whether the perceived aspect ratio of city squares was affected by the position of the observer on the square. In the first experiment, participants were asked to set the aspect ratio of a small rectangle such that it matched the perceived aspect ratio of the city square. In the second experiment, participants were asked to estimate the length and width of the city square separately. In the first experiment, we found that the perceived aspect ratio was in general lower than the physical aspect ratio. However, in the second experiment, we found that the calculated ratios were close to veridical except for the most elongated city square. We conclude therefore that the outcome depends on how the measurements are performed. Furthermore, although indirect measurements are nearly veridical, the perceived aspect ratio is an underestimation of the physical aspect ratio when measured in a direct way. Moreover, the perceived aspect ratio also depends on the location of the observer. These results may be beneficial to the design of large open urban environments, and in particular to rectangular city squares.

Keywords: scene perception, vision, public spaces, city squares, space perception.

1 Introduction

We often pay little attention to the dimensions of the space that surrounds us. Even when sitting down for a drink on a market square, the aim is usually to enjoy ourselves and watch other people rather than to observe the aspect ratio of the market square. Nevertheless, the perceived aspect ratios of public spaces seem important design considerations to use in architecture with likely implications for the perceived "atmosphere," "spaciousness," or "openness" of them. You would expect that one would want to know what the perceived characteristics are before undertaking such large building projects that may determine the appearance of a city for centuries. Even though we rarely notice that our visual perception is not in agreement with physical reality, a large body of research has shown convincingly that visual space is considerably distorted, particularly in the depth direction. See for example Gillam (1995) or Hecht, van Doorn, and Koenderink (1999) for a review. Distances are for example often underestimated and may even depend on the texture of the ground surface (Sinai, Ooi, & He, 1998). However, detailed quantitative data on how the perceived aspect ratio of public spaces is related to physical parameters are sparse. There are some documented cases where the physical aspect ratio was manipulated so as to obtain a certain perceptual effect. Panofsky (1925) for example reported that the perceived aspect ratio of the St Paul's square in the Vatican is circular. However, actually, it is an oval with an aspect ratio of roughly 1.4 (as measured on Google Maps, satellite image). In the present study, we wanted to find out (1) how the aspect ratios of large public spaces are perceived, (2) how observers' aspect ratio estimates relate to observers' distance estimates, and (3) how the perceived aspect ratios are affected by the viewers' position on the square.

Earlier studies have shown that there are considerable systematic distortions in the visual space in the psychophysics laboratory (e.g. Cook, 1978; Foley, 1980) as well as in large, open, outdoor spaces (e.g. Hecht et al., 1999; Higashiyama, 1996; Koenderink, van Doorn, Kappers, & Lappin, 2002; Levin & Haber, 1993; Wagner, 1985). In particular, distances are usually underestimated, that is a depth compression, relative to fronto-parallel distances (e.g. Loomis, da Silva, Fujita, & Fukusima, 1992; Loomis, da Silva, Philbeck, & Fukusima, 1996; Wagner, 1985). Wagner for example measured perceived distance, perceived angles, and perceived area spanned by arbitrarily positioned flag-poles in a large open field. Wagner found that there was a considerable compression in the "in-depth" dimension relative to fronto-parallel distances. Likewise, there were considerable flattening effects of perceived angles. Hecht et al. (1999) also reported a tendency for observers to perceive angles on buildings to be less pointed or obtuse than veridical. Loomis and Philbeck (1999) raised the questions whether the in-depth compression, which they termed the anisotropy of the visual scene, is invariant for different scales. Loomis and Philbeck used an L-shaped probe that was placed in the scene to measure the perceived aspect ratio at different locations in the scene. Interestingly, they found that the anisotropy was invariant across scale for monocular viewing, but not for binocular viewing. They attributed this finding to the fact that the reliability of binocular disparity as a depth cue falls off with increasing distance to the observer.

He, Wu, Yarbrough, and Wu (2004) argued that the visual system builds a sequential representation of the world starting with a ground surface area with a clear optical gradient close to the observer. They refer to this model as the sequential-surface-integration-process (SSIP). The ground surfaces farther away are "glued" to the closer areas. However, with increasing edges and occlusions in the ground surface textures, the representations are more and more biased toward a default value leading to an increasing compression in the depth dimension as well as an upward slope of the perceived ground surface. Ooi, Wu, and He (2006) used local luminous L-shaped probes viewed in otherwise complete darkness. They measured perceived egocentric distance to the probes using a blind-walking paradigm. They found that the perceived aspect ratio was indeed related to the perceived distance. Li and Durgin (2010) also found, in agreement with the SSIP, that the perceived slope of ground surfaces was exaggerated with increasing distance from the observer. From the studies mentioned above, it is hard to predict what would be the perceived aspect ratio of a large space, such as a city square that completely surrounds the observer. First, the observer is not merely judging distance but rather a ratio of orthogonal distances. And, the latter is not necessarily done by independently estimating length and width. Second, the typical sizes of city squares are much larger than the ranges that are typically described in the vision literature. Scale is an important consideration in the present context because at such large sizes as city squares, the accuracy of binocular disparity as a depth cue rapidly decreases with increasing distance (see for example Loomis & Philbeck, 1999). Third, city squares are closed spaces. That is, they are delimited by houses and walls and are not drawn on the ground plane of an otherwise open field. The SSIP (He et al., 2004) predicts that the anisotropy of the visual space increases with increasing number of ground surface edges and occlusions. Fourth, no previous studies have reported what the perceived aspect ratio of the entire space is for large closed spaces such as city squares. Previous studies have measured the perceived local aspect ratio in the scene instead of the shape of the entire space in which the observer is located (e.g. He et al., 2004). And, finally, it is also not immediately evident whether the location of the observation point within a certain environment matters.

Let us consider a naive model in which distances in depth are always underestimated relative to lateral distances. And let us further assume that when the observer is standing at the edge of a city square, the distance in front of the observer to the opposing facade is the depth dimension and the distance between the two lateral facades of the city square is the lateral distance. In that case, the observation point should matter on a city square when judging its aspect ratio, which we define here as the ratio of the long side over the short side of the city square: If standing on the long side of a rectangular city square, the depth dimension is the short side of the city square, whereas if one is standing on the short side, the depth dimension is the long side. It is also reasonable to consider the perceived aspect ratio as the ratio of the perceived distances rather than the physical distances. Stevens (1975) argued that perceived intensity could be described for many modalities as a power function of physical intensity. In our naive model, we also express the perceived distance as a power function. Given a constant depth compression factor, the perceived aspect ratio would then respectively be as in Equations (1a) and (1b):

Standing on the short side:

$$\hat{\rho} = (c * l)^a / w^a = c^a \rho^a. \tag{1a}$$

Likewise, standing on the long side:

$$\hat{\rho} = l^a / (c * w)^a = c^{-a} \rho^a, \tag{1b}$$

where $\hat{\rho}$ is the perceived aspect ratio and ρ is the physical aspect ratio (length/width). l is the physical distance along the long side of the city square (that is, the length), and w along the short side of the city square (that is, the width). The parameter c indicates the compression factor in depth relative to the width and is applied to either the width or the length of the city square depending on the observation point. Therefore, the viewpoint would matter for the perceived aspect ratio. We did thus not add a specific parameter for compression in the lateral dimension because the depth compression factor, c, is a relative parameter with respect to the lateral compression. The power exponent is indicated by the parameter a. Please note that the absolute size has dropped out of Equations (1a) and (1b), but that the exponent a is maintained.

In Figure 1(a), we have plotted how the perceived aspect ratio would be affected by viewing position when the distance in depth is underestimated by a factor of 0.75 relative to the lateral distance and an exponent a of 1. The dashed red and blue curves are for standing on the short respectively the long side. Figure 1(b) shows how the perceived aspect ratio would change as a function of the physical aspect ratio with a compression factor c of 0.75 and an exponent a of 0.75. As can be seen in Figure 1(b), with a power exponent of less than 1, the perceived aspect ratio increases progressively less than the

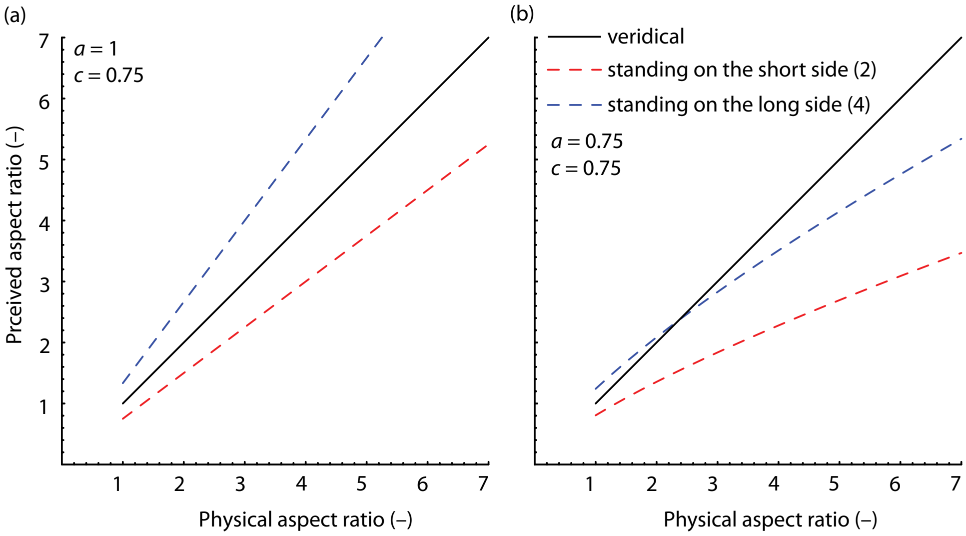


Figure 1. (a) Predicted perceived aspect ratio as a function of the physical aspect ratio of the city square with a depth compression factor c of 0.75 and an exponent a of 1, for standing on the short side (red dashed line) or on the long side (blue dashed line) as modeled in Equations (1a) and (1b). A veridical percept (that is a depth compression of 1) is shown as a solid black line. (b) Predicted perceived aspect ratio as in panel (a), but now implementing an exponent a of 0.75 and a depth compression of 0.75. Note that the blue and red lines are straight in the left panel but slightly curved in the right panel.

physical aspect ratio. For a power exponent larger than 1, the perceived aspect ratio would become progressively more than the physical aspect ratio. Note that at this point in the paper the values for *a* and *c* have been chosen for illustration reasons only. However, compression factors *c* of 0.75 and exponents *a* of 0.75 are not unreasonable choices given the literature (e.g. Loomis et al., 1996; Wagner, 1985). Wagner for example reports that fronto-lateral distances were perceived as about twice the size of distances in the "in-depth" dimension. Several other distance–depth relations have been put forward in the literature (e.g. Gilinski, 1951; Luneburg, 1947, 1950). Equations that are similar to Equations (1a) and (1b) in their effect of viewing position can be derived from these distance–depth relations such as the Gilinski (1951) distance function, although in that particular case the absolute distance does not drop out of the aspect ratio equations as it does in Equations (1a) and (1b) in the current paper. That is, the absolute size of a city square would be a factor in the Gilinski equation, whereas in our model absolute size is irrelevant. Note also that we have assumed the values of *a* and *c* to be constant across the entire visual field although that would not necessarily be the case (cf. Koenderink, van Doorn, & Lappin, 2000; Wagner, 1985).

As demonstrated above, there are some relatively simple reasons to expect effects of observer position on the perceived aspect ratio of large public spaces but whether the perceived aspect ratio can be modeled as such remains to be determined experimentally. It is for example a priori not unthinkable that both the width and length of the city square are considered by the observer as egocentric, that is "in-depth" distances. Then, the compression factor *c* would apply equally in every direction. In that case, there would not be an effect of viewing position at all. In order to determine what people see, we asked observers in two experiments to make direct aspect ratio and distance estimates at five different positions on five different city squares in Delft, the Netherlands. In the first experiment, participants set the aspect ratio of a small handheld rectangle to match the perceived aspect ratio of the city square directly. In the second experiment, participants were asked to report the city square's perceived length and width separately.

2 Method

The participants and locations were the same for both experiments. They differed only in the tasks, which are described in Sections 3.1 and 4.1, respectively.

2.1 Participants

Six female and five male (under)graduate students at the Delft University of Technology took part in both experiments. All participants reported having normal or corrected-to-normal vision. They received a compensation of 10 euro per hour for their participation. All participants were naive and gave written, informed consent. Being local students, the participants were of course familiar with the city center of Delft. All experiments were in agreement with local ethical guidelines, Dutch Law and the Declaration of Helsinki.

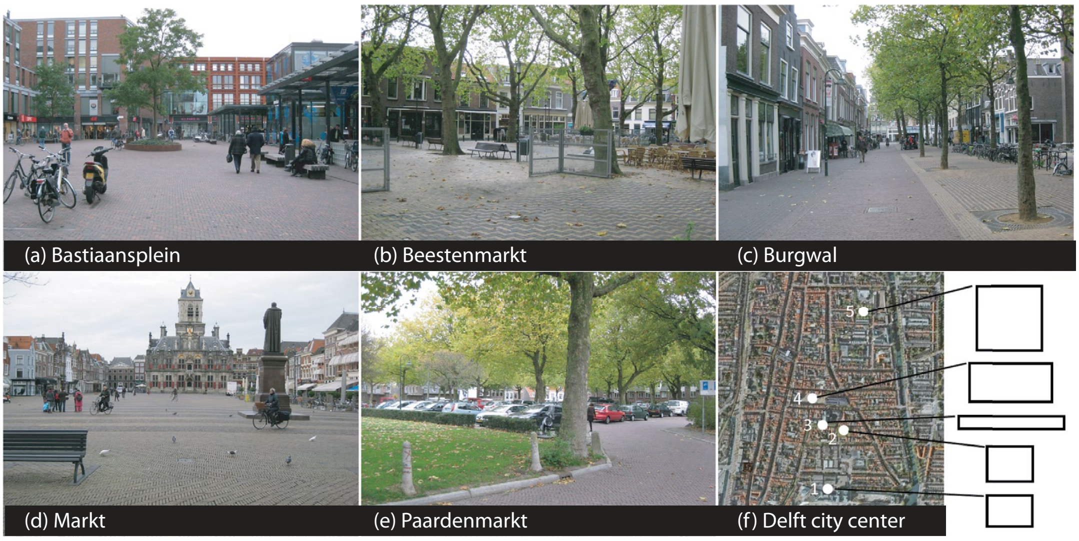
2.2 Locations

We did the experiments on five different public squares in the historical city centre of Delft, the Netherlands, namely Bastiaansplein, Beestenmarkt, Burgwal, Markt, and Paardenmarkt. Photographic impressions of these five squares, their locations and their aspect ratios are shown in Figure 2. All five squares are within walking distance of each other. We measured all city squares' dimensions manually using a 100-m measuring tape. The five city squares were chosen such that they covered a range in aspect ratio from about 1.0 to as large as 7.1. The true physical dimensions of each city square are summarized in Table 1.

On each city square we defined five observation points as shown in Figure 3. The observation points were marked with numbered (10 cm high) flags stuck into the pavement.

2.3 Procedure

Both experiments were conducted over a period of two days with five participants on day 1 and six participants on day 2. The weather on day 1 was cold and sunny, whereas day 2 was cold and cloudy. The experiments took about five hours per day in total. The order in which the squares were visited on day 1 was Bastiaansplein, Beestenmarkt, Burgwal, Markt, and Paardenmarkt. The order was reversed on day 2. On each city square, the five observation points were visited twice by all participants in the same order. In the first pass, participants did the task for Experiment 1 and in the second pass they did the task for Experiment 2.



(a) Bastiaansplein (b) Beestenmarkt (c) Burgwal

(d) Markt (e) Paardenmarkt (f) Delft city center

Figure 2. Photographic impressions of (a) Bastiaansplein, (b) Beestenmarkt, (c) Burgwal, (d) Markt, and (e) Paardenmarkt; (f) a map of Delft Centre on which are indicated the locations of the five squares (lower right). The physical aspect ratios of the rectangular shapes of the city squares are shown next to the map.

3 Experiment 1

3.1 Task

At each observation point on a city square, participants were asked to turn and look around 360 degrees (on the spot) and subsequently adjust the two sliders on a device for masking photographs (an Easel Mask from LPL Co. Ltd., shown in Figure 4) such that the aspect ratio of the rectangle on the device resembled the perceived aspect ratio of the rectangular shape of the city square. The participants were notified that the task comprises the *perceived* shape, and not their best cognitive guess. The units on the rulers on the sides were removed. The setting of the sliders was recorded by drawing the resulting aspect ratio on an underlying piece of paper. The device was always held in portrait orientation with the sliders at the left and the bottom. Participants were also asked to indicate their relative orientation on the city square with a little “x” on the paper.

3.2 Results

We measured the length and width of the rectangles drawn by the observers. We divided the length by the width to obtain what is henceforth called the *indicated aspect ratio*.

The indicated aspect ratios averaged across participants are shown in Figure 5(a) for each observation point on the five city squares. The error bars indicate the standard error of the mean. At a first visual inspection of Figure 5(a) it can be seen that the indicated aspect ratios are in general lower than the physical aspect ratio. The difference between the two is getting larger with increasing physical aspect ratio of the city square.

We did a 5 × 5 (city square × observation point) repeated measures ANOVA with the indicated aspect ratio as the dependent variable and participants as independent replications. We applied a Greenhouse-Geisser correction on the degrees of freedom for the main effect of city squares and its

Table 1. The physical length, width, and aspect ratio of the five city squares that were used in this study, in order of increasing aspect ratio.

City square	Length (m)	Width (m)	Ratio (–)
Paardenmarkt	98.2	97.2	1.01
Beestenmarkt	70.2	54.1	1.30
Bastiaansplein	69.5	48.5	1.43
Markt	122.9	58.8	2.09
Burgwal	155.3	21.8	7.12

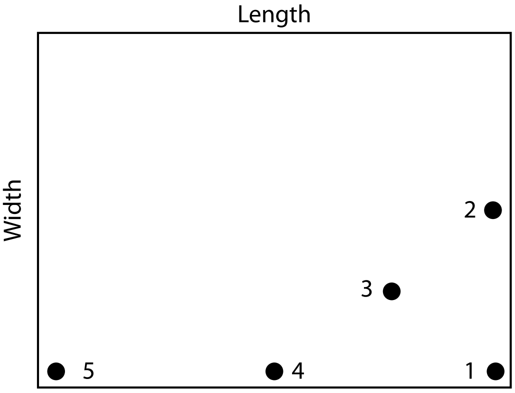


Figure 3. On each city square five observation points were defined (1) in a first corner, (2) halfway along the short side, (3) on a quarter of the diagonal, (4) halfway on the long side, and (5) in a second corner. The first corner was chosen such that it allowed a clear view of the city square, minimizing obstructions and distractions. The observation points on the "Beestenmarkt" were defined as a mirror image of Figure 3.

interaction effect in order to correct for non-sphericity. There were significant main effects of the city square ($F_{1.7,\,16.8} = 106.92$, $p < 0.000$) and the observation point ($F_{4,\,40} = 7.92$, $p < 0.000$). There was also a significant interaction effect between the city square and observation point ($F_{4.2,42.2} = 3.11$, $p < 0.023$). Because we had a different group of participants each day, we have run the above ANOVA with *day* as a between-participants factor. There were however no significant group differences. There were also no significant group effects when gender (male/female) was included as a between-participants factor.

We then fitted the two models developed in Equations (1a) and (1b) simultaneously to the data using a least-squares criterion, with the physical aspect ratio and the observation point (2 and 4) as predictor values. If the value for the observation point was "two," then Equation (1a) was used, else Equation (1b) was used. When averaging the data across participants, we found a depth compression factor c of 0.85 (95% CI = [0.74–0.96]) and an exponent a of 0.5 (95% CI = [0.46–0.55]). Values for fitting the model separately for each participant ranged for the depth compression factor c between 0.69 and 1.11 and for the exponent a between 0.31 and 0.61. We have plotted the data and the best-fitting model in Figure 6(a).

3.3 Summary

The indicated aspect ratio was lower than the physical aspect ratio for four of the five city squares. Only for the Paardenmarkt, which has a physical aspect ratio close to 1, was the indicated aspect ratio

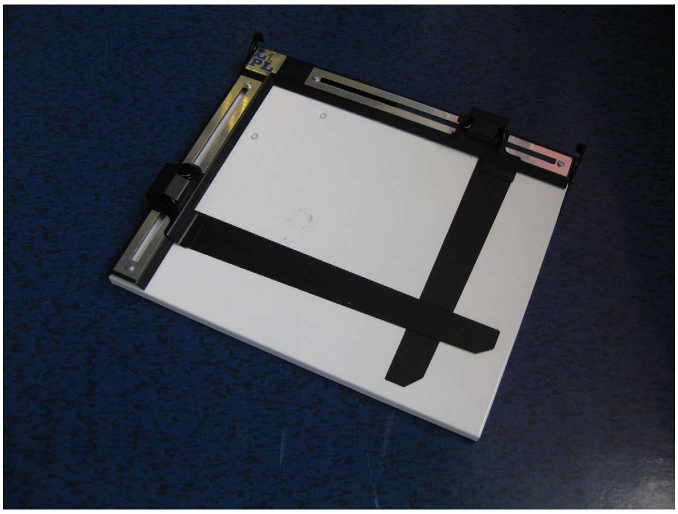


Figure 4. The mobile device for measuring the perceived aspect ratio. The two black rulers can be moved independently of each other. In the experiment, the tablet was mounted on a wooden panel for ease of handling.

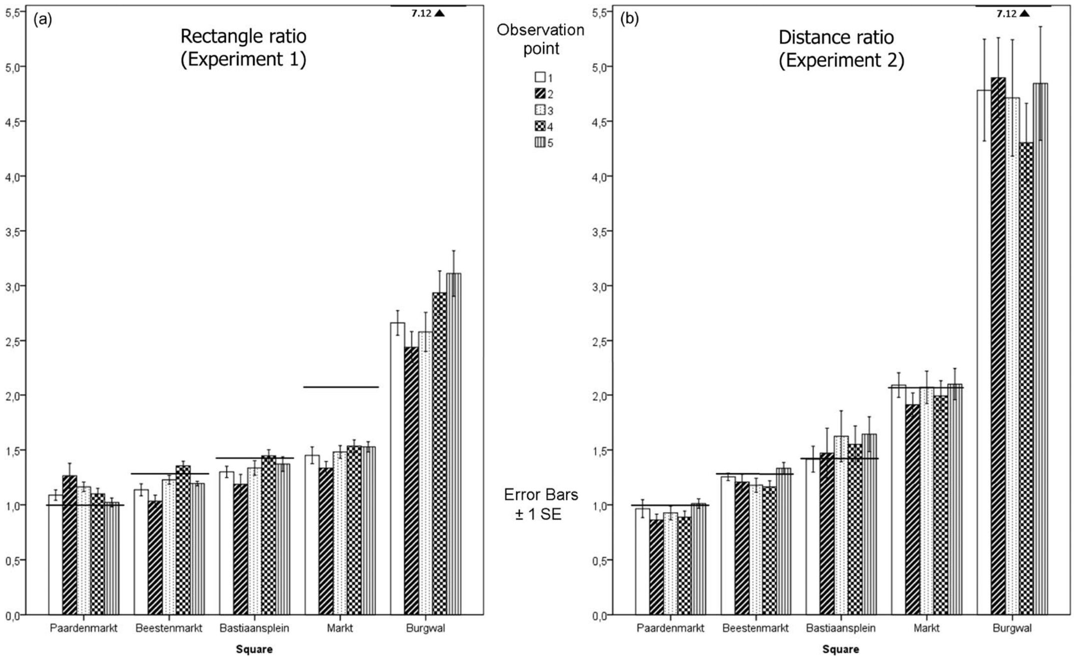


Figure 5. (a) The indicated aspect ratios for each city square and observation point averaged across participants for Experiment 1. (b) The calculated distance ratios for each city square and observations point averaged across participants for Experiment 2. The horizontal black lines represent the true physical ratio of each city square.

higher than the physical aspect ratio. There were significant main effects of both differences between city squares and also between different observation points.

The indicated aspect ratios were lower at observation point 2 (midway the short side of the city square) than at observation point 4 (midway the long side of the city square). The fact that our results could be fitted with our model suggests that there is indeed a compression factor in depth relative

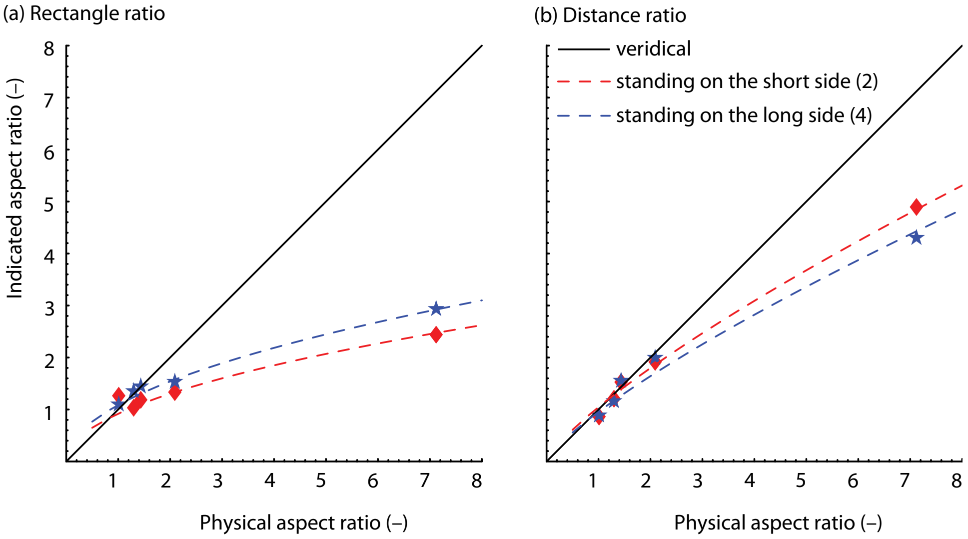


Figure 6. (a) Data averaged across participants for observation points 2 and 4, with the best fitting fit to the model in Equations (1a) and (1b) for Experiment 1, namely a compression factor *c* of 0.85 and a power exponent *a* of 0.50. The red line is the fitted indicated aspect ratio as seen from the short side (obs point 2) and the blue line is the fitted indicated aspect ratio as seen from the long side (obs point 4). The black solid line is where the indicated aspect ratio equals the physical aspect ratio. (b) Data averaged across participants, with the best fitting fit to the model in Equations (1a) and (1b) for Experiment 2, namely a compression factor *c* of 1.05 and a power exponent *a* of 0.78. The color code is as in panel (a).

to lateral distances. Furthermore, the underestimation of the aspect ratio increases with increasing physical aspect ratio as predicted by assuming that distance estimation increases as a power law with increasing physical distance.

4 Experiment 2

In the second experiment, we wanted to find out whether the results are task dependent. In this experiment, we asked people to make separate judgments of the perceived length and width of the city squares. From these two distance estimations, we calculated the aspect ratio by simply dividing the two. The obtained ratio from the separate length and width estimates is henceforth called the *calculated distance ratio*.

4.1 Task

At each of the five observation points on each square, the participants were asked to estimate two distances, namely the length and the width of the city square. The participants were asked to estimate how many times a stick of approximately 1.2 m fitted in each distance. It was explicitly emphasized that it was their perception that counted, and that they had to reconsider their estimates anew at each viewing position. During the task, the stick was held horizontally and frontally in the field of view of the participants by one of the experimenters. Participants were not told the exact length of the stick in centimeters to prevent interference of prior knowledge of sizes and distances in known units, such as meters.

4.2 Results

The calculated distance ratio for each city square and observation point is shown in Figure 5(b). On a first visual inspection of Figure 5(b), it may be seen that the calculated distance ratios, determined in this indirect way, are close to veridical except for the most elongated city square, that is Burgwal, which showed a calculated distance ratio that is considerably lower than the physical aspect ratio.

As in Experiment 1 we did a 5 × 5 (city square × observation point) ANOVA with repeated measures. We applied a Greenhouse-Geisser correction to the degrees of freedom for city square and its interaction effect. There was a significant main effect of the city square ($F_{1.5,15.0} = 65.76$, $p < 0.000$) but there was no significant main effect of the observation point ($F_{4,40} = 1.29$, $p < 0.290$) and there was no significant interaction effect ($F_{3.1,31.4} = 0.639$, $p < 0.603$). We also did the ANOVA with *day* and *gender* as independent between-groups factors in the design, but, as in Experiment 1, there was neither a significant effect of day nor of gender.

We then fitted the two models developed in Equations (1a) and (1b) simultaneously to the data using a least-squares criterion, with the physical aspect ratio and the observation point (2 and 4) as predictor values. If the value for the observation point was "two," then Equation (1a) was used, else Equation (1b) was used. When averaging the data across participants, we found a compression factor c of 1.06 (95% CI = [0.99–1.13]) and an exponent a of 0.78 (95% CI = [0.74–0.81]). Values for separate fits for each participant ranged between 0.91 and 1.25 for the compression factor c and between 0.59 and 0.93 for the exponent a. The best-fitting model is shown in Figure 6(b).

Finally, we calculated the correlation across participants between the mean indicated aspect ratios across all city squares and observations points, and the mean calculated distance ratios across all conditions. The R^2 was no larger than 0.002.

4.3 Summary

The averaged calculated distance ratios were close to veridical for all city squares, except for the most elongated city square, the Burgwal. In contrast to Experiment 1, we did not find a significant dependency of the distance ratios on the observation point. When fitting the model from Equation (1), we found that the compression factor c was larger than 1 (but as already suggested by the above ANOVA results, a value of 1 was within its confidence interval). The exponent a was significantly lower than 1, indicating that the aspect ratio was progressively more underestimated when the city square was more elongated.

5 Discussion

In both experiments, we convincingly found that observers were indeed able to estimate the city squares' aspect ratios, and that in both cases their estimates increased monotonously with the physical aspect ratio. However, there were some marked differences between the results of Experiments 1 and 2.

In Experiment 1, we found that participants underestimated the aspect ratios of city squares, irrespective of the observation point, except when the city square's aspect ratio was close to 1 (Paardenmarkt). In Experiment 2, the calculated distance ratio was only lower than the physical ratio for the most elongated city square (Burgwal) while the calculated distance ratios for the other four city squares were close to veridical. Taken all together, we could say that the underestimation of the aspect ratio was getting more pronounced when the city square was more elongated and that it was more pronounced for Experiment 1 than for Experiment 2.

The indicated aspect ratio was typically smaller than the actual aspect ratio, except for the smallest physical aspect ratio (1). In this case, the aspect ratio was slightly overestimated. Taken as a whole, these results suggest that the aspect ratio is biased toward some intermediate value. Indeed observers prefer a template over a "correct" setting. These findings are very hard to explain in terms of a model of vision as inverse optics. Apparently, observers are hardly concerned with the issue of veridicality. There is no evolutionary pressure toward veridicality as such. Rather, the evolutionary pressure is toward optimal efficaciousness in the interaction with the world that relies on optical factors. But a demand for optimal efficaciousness runs counter to a demand for veridicality (Hoffman, 2009; Mark, Marion, & Hoffman, 2010). Agents need a fast and reliable optical interface, rather than a system that builds a veridical representation (Koenderink, 2010).

We also found indications that the observation point had an effect on the direct measurements (Experiment 1) of the perceived aspect ratio consistent with a compression factor c in depth lower than 1. A depth compression factor c of 0.85 seems in line with previous findings in the literature (e.g., Wagner, 1985). However, in Experiment 2, using the indirect method of letting observers estimate length and width independently, we found that all observation points were not significantly different from a compression factor equal to 1. The difference in the results of Experiments 1 and 2 suggests to us that observers may be judging the aspect ratio in Experiment 1 as if one dimension of the square is a "dimension in depth," and a second dimension is a "lateral" dimension, whereas in Experiment 2, both dimensions may be seen as egocentric distances. That is, in Experiment 2, when only one distance is estimated at the time, the lateral distance may also be estimated as if it is an egocentric distance, for example by summing the distances from the self to nearest parts of the lateral facades rather than looking across the city square to judge the distance along the frontal facade. Other explanations are possible; the current explanation is just one of them.

Why the exponent a is so much smaller in Experiment 1 (0.5) than in Experiment 2 (0.78) is not clear. We also found that there was no correlation across participants between Experiments 1 and 2. In other words, it is not predictable on the level of the individual what the perceived aspect ratio of a city square will be using different tasks to measure the perception of the same city square. At present, we have no explanation for these two findings. The fact that the observers' task can affect perception can however readily be found in the literature (e.g., Koenderink, van Doorn, Kappers, & Todd, 2001; Li & Durgin, 2010).

In conclusion, first, in general the length/width aspect ratio is underestimated. Second, the underestimation is larger in a direct task than in an indirect task. And, third, the observation point matters when the aspect ratios are measured in a direct manner, with larger underestimations of the aspect ratio when standing on the short side of the city square than when standing on the long side. Given the sizes of the effects reported in the current paper, it seems prudent in urban planning to consider not only the physical aspect ratio but also the manner in which the city square is to be typically perceived and where the principal viewing points on the city square are.

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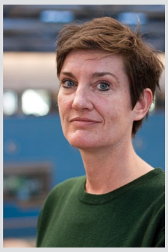

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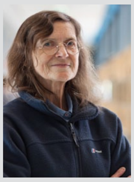

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