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Two dimensions of visibility revealed by multidimensional scaling of metacontrast

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ABSTRACT

An increasing number of studies use subjective reports of visibility, so as to delineate the domain of perceptual awareness. It is generally assumed that degrees of visibility can be ordered on a single unidimensional scale. Here, I put this assumption to test with metacontrast, one of the most studied visual masking paradigms. By means of multidimensional scaling, I show that even though metacontrast stimuli only differ along the dimension of time, the perceptual space they generate unfolds in three dimensions: time and two kinds of visibilities, that are confounded when projected onto a unitary visibility scale. I argue that metacontrast creates multidimensional complex percepts, a property that may run counter to its use as a simple modulator of visibility. More broadly the results cast doubt on the use of visibility scales that ignore the qualities of the percepts.

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1. Introduction

The emergence of a scientific study of consciousness has been accompanied by the development of a vast array of new methods and measures. Among these methods is the use of subjective visibility scales (see for instance [Sergent & Dehaene, 2004](#); [Ramsøy & Overgaard, 2004](#)). These measures are meant to capture participants' subjective impression of seeing. It is argued that subjective measures better correspond to conscious awareness of the stimulus than performance in a forced choice task (detection or discrimination), as is traditionally used in psychophysics, since forced choice performances can be influenced by unconscious processing. However, these methods all come with the implicit assumption that visibility can be gauged on a

single ordered dimension.¹ Here, I put this assumption to test on the case of metacontrast stimuli.

Metacontrast is one of the most often used and most studied (see [Breitmeyer & Ögmen \(2006\)](#), for a comprehensive review) methods for masking a visual stimulus, i.e. to modulate its visibility. Metacontrast is produced when a brief stimulus (the target) is followed by a second brief stimulus (the mask) that surrounds and abuts it without overlap. When the interval between the two stimuli is below around 150 ms, the second stimulus profoundly modifies the visibility of the first stimulus, to the extent that its features may become indiscriminable, and that, in some cases ([Otto, Ögmen, & Herzog, 2006](#)) the target itself may be invisible. Since the first observations made by [Stigler \(1910\)](#), it has been extensively used both as a tool for the study of early vision, and as a method for the fine control of visual awareness.

However, there is more to metacontrast than visibility. In metacontrast, time, most often operationalized as the

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¹ Notice that this assumption is also implicit when visibility is computed as the mean of seen/not seen judgments as in [Lau and Passingham \(2006\)](#).

Stimulus Onset Asynchrony (SOA) between the target and the mask, varies along a single dimension. Perhaps surprisingly, this unidimensional manipulation creates a host of quite different phenomena. For instance, the mask impacts both the apparent brightness of the target and its perceived contour (Breitmeyer et al., 2006), while these effects have different and distinctive timecourses – the “metacontrast functions” that relates the target/mask SOA to the measured effect. Moreover, metacontrast does not simply modify the visual features of the target, but also its position in time and space: perceived onset time of the target (Didner & Sperling, 1980) and estimates of the target’s spatial position (Sigman, Sackur, Del Cul, & Dehaene, 2008) are both shifted by the mask. While all these effects show a massive backward influence of the mask on the target’s percept, simple response times to the target are not affected by the mask (Fehrer & Raab, 1962; Neumann & Scharlau, 2007; Raab et al., 1961, but see Proctor, Bernstein, & Schurman, 1974). Similarly, Vorberg, Mattler, Heinecke, Schmidt, and Schwarzbach (2003) found that the timecourse of the motor priming effect of a target was unrelated to whether it was masked or not by metacontrast, suggesting again that metacontrast selectively modulate some aspects of target processing while sparing others (see also Kunde, 2003, who extends the dissociation at the level of control mechanisms).

Interestingly, the effect of metacontrast is quite often a non-monotonic function of the SOA: Performance on shape discrimination and ratings of the visibility of the target may start at a high value for short SOAs, then decrease at intermediate ones and rise again and plateau for long SOAs (U-shaped, “type B” metacontrast). But the U-shaped timecourses of visibility and discrimination or detection performances are not always exactly parallel. Thus one can sometimes find two SOAs across the trough of the metacontrast function such that performance is equated while visibility is lowest for the shortest SOA (“relative blindsight”, Lau & Passingham, 2006; Jannati & Di Lollo, 2011). This shows how promising a tool metacontrast is for the study of visual awareness, since it may enable a measure of “pure” visibility (be it about the target’s presence, or most often about the discriminability of the target’s features), unadulterated from behavioral performance differences.

However, even though metacontrast is very often used as a tool for the control of visibility, one should not forget that it is a multidimensional phenomenon. As such it affords multiple “criterion contents” (Kahneman, 1968): Observers can use many different cues, on various dimensions, when asked to process a metacontrast stimulus. This might be particularly true when observers are asked to rate the visibility of the target, as visibility is a very broad construct. What it means “to see or not to see” a target when it is masked by metacontrast can have many different meanings for different observers in different conditions. Yet, while criterion content has been recognized as potentially critical in metacontrast for a long time, it has rarely been at the top of metacontrast researchers’ agenda. One reason for this situation is, as Bernstein, Fiscaro, and Fox (1976) point out, that a thorough study of criterion content seems to require that one rely on subjective verbal descriptions of

experience – which Bernstein et al. (1976) eschewed by relying on discriminant function analysis.

Thus, despite its obvious multidimensional nature, most extant studies of metacontrast have relied on predefined scales to measure the effect of the mask (apparent brightness, contour discrimination, visibility of the target, etc.), thereby imposing the perceptual dimension along which the stimulus is to be assessed. This state of affairs may obscure the correspondence of the scales investigated with the subjective dimensions of metacontrast, as well as observers’ ability to select some specific dimension best suited for the task at hand. As a first foray into these questions, I used Multidimensional Scaling, which is based on subjective similarity judgments, and not on complex verbal reports, in order to unfold the underlying perceptual space of metacontrast. This allows me to test whether visibility of the target is among the “natural” dimensions of metacontrast.

Multidimensional scaling (MDS, Shepard, 1980) is used to recover the overall structure of the subjective space for a class of representations, based on pair-wise similarity judgments. Subjective similarities may be thought of as distances in psychological space. In MDS, one tries to go from the matrix of all pairwise distances to the map that may have generated it, with as little distortion as possible. The percepts generated by a set of N stimuli can be represented in a $N - 1$ dimensional space, without distortion, provided that similarities are *bona fide* distances. But of course, the goal of the procedure is to find some lower dimensional space, the dimensions of which we can interpret. The distortion thereby introduced (technically the “stress”) is then conceived as unexplained variance. Following this logic, I devised an experiment where, on each trial, I presented observers with two metacontrast stimuli, and asked them to rate their similarity. Stimuli differed only as regards SOAs, while all other properties were identical. To compare the MDS results with more traditional measures and facilitate interpretation, in a separate experiment, I collected discrimination performances and visibility judgments. Furthermore, to assay the separability of visibility of the target from other perceptual dimensions, I created two instructions sets, asking observers either to rate the similarity of the targets alone or to rate the overall similarity of the target and mask compound. Thus I report results of two multidimensional scaling experiments, that only differ with respect to instructions, and of one discrimination/visibility experiment. As these three experiments are based on the same stimuli, and as the discrimination experiment was ran only as an aid to the interpretation of the multidimensional results, the three experiments will be described and analyzed conjointly.

2. Material and methods

2.1. Participants

Twenty-five observers from a pool of students (8 males, ages ranging from 19 to 26) participated in the Multidimensional scaling experiments, for one session that lasted approximately 45 min. A different group ($N = 21$, 9 males,

ages ranging from 20 to 27) of similar observers participated in the one hour discrimination experiment. None were experienced psychophysical observer, and all were naive to the intent of the experiment. They all had normal or corrected to normal vision.

2.2. Stimuli

Observers sat 80 cm from a Sony Trinitron CRT screen with a refresh rate of 100 Hz and a resolution of 1024×768 pixels (pixel size: 0.0215°) in a dimly lit experimental booth. The target was a square (25 pixels, $.54^\circ$), while the mask was a square annulus (35 pixels, outer width, $.75^\circ$), with no intervening gap between the target and the mask. Stimuli were black (4 cd/m^2), while the rest of the screen was a light gray (23 cd/m^2). A trial (see Fig. 1A) consisted first of a fixation cross ($.1^\circ$, 700 ms) at the center of the screen, then the two target–mask pairs, one above and one below fixation (eccentricity: $.86^\circ$), with a fixed inter-pair interval of 500 ms . Durations of targets and masks were respectively 20 and 30 ms . Finally, a horizontal scale with seven cells appeared, of which only the endpoints were labeled as “Totally different” and “Perfectly alike” (in French, see below for the precise tasks and instructions). On each trial one random cell was highlighted. Observers moved the highlighted cell with the arrow keys on a standard keyboard, and validated their

response with the space bar. In order to improve observers’ judgment quality, they could replay the two pairs before entering their judgements. Five observers never did so, while the proportion of retries was $.34$ ($sd = .36$).

I used all SOAs in the range 0 – 150 ms in steps of 10 ms , and presented the full 16×16 combinations. Thus the pairs with different SOAs were presented twice (with position above or below fixation reversed), while the pairs with identical SOAs were presented once.

2.3. Procedure

To begin, observers were twice shown the full randomized list of target–mask pairs in a familiarization block where the two pairs above and below fixation were identical; observers were apprised of this and were instructed to practice the use of the scale by bringing the highlighted cell back to the “exactly identical” end. After these 32 trials, observers were presented the randomized 256 trials of the main scaling experiment, with *ad lib.* pauses every 32 trials.

2.4. Instructions

Two instruction sets were used: in the *holistic* instruction set, observers ($N = 10$) were asked to rate the global similarity of the two target–mask pairs. They were

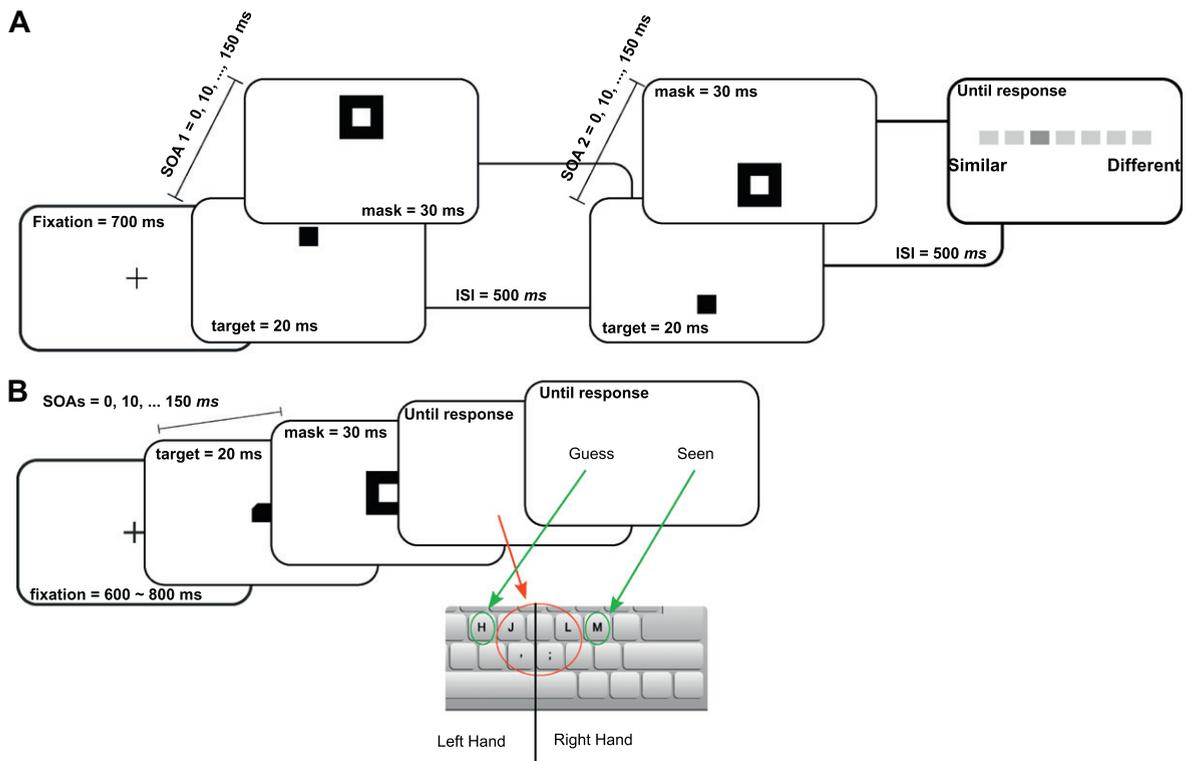


Fig. 1. (A) Trial structure for the main scaling experiment. Two target–mask pairs were shown, one above and one below fixation, and participants rated their similarity. Note that if participants were unsure about their response, they could replay the trial by hitting the *R* key on the scale screen. (B) Trial structure for the discrimination and visibility rating experiment. Notice the dent in one of the target’s corner. For the discrimination task, participants used the *J*, *L*, comma and semi-colon keys (French keyboard, red color code); they used the *H* and *M* key for the visibility task (green color code). Sides for “seen”/“not seen” were counterbalanced across participants. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

requested to consider each target – mask pair as a complex visual event, and to judge to what extent these two complex events were similar. In the *focal* instruction set observers ($N = 15$) were instructed to focus their judgments on the target and factor out the mask. Importantly, as is customary in multidimensional scaling procedure, the instruction sets did not highlight which aspect or dimension of the stimuli were to be used in the similarity ratings. Thus, instructions differed only with respect to *what* to observe, not about *how* to judge similarity.

2.5. Discrimination and visibility ratings

For the control discrimination experiment, stimuli matched those of the MDS experiment, except that the target had a small ($.064^\circ$) notch in one corner. Following the methodology of Lau and Passingham (2006), on each trial (see Fig. 1B) observers first performed a four Alternative Forced Choice task on the position of the missing corner, and then reported whether they saw the target or simply guessed.

3. Results

3.1. Preliminary analyses: two dimensional MDS and discrimination results

First, I wanted to ascertain that the multidimensional scaling procedure was able to recover some well-known properties of metacontrast. To this end, I applied a classic two dimensional MDS and compared it to the results of the traditional discrimination and visibility experiment. For each stimulus pair, I averaged all similarity judgments (two repetitions per participants) over participants, for both instruction sets.² Here, I aggregated both instruction sets, as this was simply a preliminary analysis meant to assay the soundness of the technique. Responses on the similarity scale were coded linearly from 0 (“Identical”) to 6 (“totally different”). I thus obtained a triangular matrix of dissimilarities which can be considered as distances. I then I submitted these distances to metric MDS, searching for a bidimensional configuration. I used the SMACOF package (De Leeuw & Mair, 2009) for the R statistical environment (R Development Core Team, 2009). Again, the choice of a 2-dimensions configuration is here simply preliminary, in order to check that there is indeed some structure in the data.

As can be seen (Fig. 2), this configuration is highly structured: increasing SOAs are distributed along a main axis, with some compression at the higher and lower ends of the interval. More precisely, we see that SOAs between 0 and 30 ms are nearly indistinguishable along this dimension, as are SOAs above 110 ms. On the contrary, SOAs between 40 and 100 ms are evenly spaced along this first dimension. A secondary axis seems to correspond to visibility, with intermediate SOAs, for which visibility of the target is known to be most impaired, being at one extreme

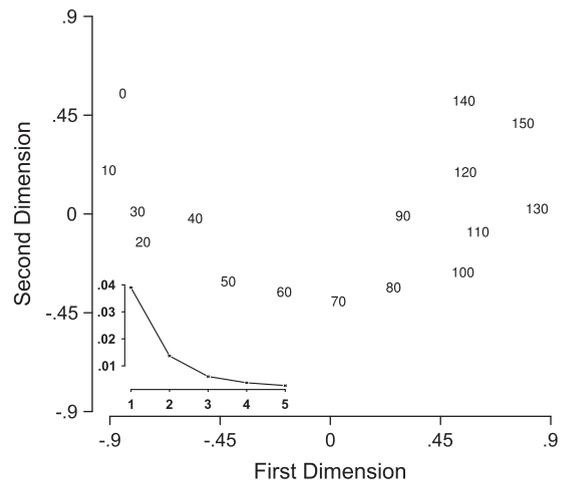


Fig. 2. Metric multidimensional scaling (MDS) two dimensional configuration for dissimilarity judgments averaged over all observers, in the two instruction sets. Numbers indicate SOAs. Inset represents the stress for the $N = 1, \dots, 5$ dimensional solutions with classical metric MDS. As can be seen, there is a sharp reduction in stress from the 1 to the 2 dimensions solution, but some improvement with the 3 dimensions solution is also apparent.

and short and long SOAs at the other. I thus recover the U-shape of the metacontrast function: physical time is monotonously mapped onto perceptual time, and visibility emerges as a non-monotonic function of perceptual time. This confirms, by novel means, that the two main axes that organize the perceptual space of metacontrast are time and visibility.

This interpretation is vindicated by the analysis of the discrimination and visibility experiment: for this experiment, I excluded three participants whose performances were overall below 65% correct, and transformed both visibility estimates and discrimination performances to d 's, assuming no bias (Green & Dai, 1991). It yielded U-shaped metacontrast functions, for both measures (see Fig. 3). In a 16×2 repeated measures ANOVA with factors of SOA and response type, and observers as a random factor, the two main effects were found significant ($ps < 10^{-6}$), but the interaction was not ($p > .8$).

Then, I regressed positions on the secondary axis of the previous two dimensional MDS group analysis on discrimination performances and visibility judgments. Both regressions were found significant ($r = .81, p < .001$ and $r = .75, p < .001$ for visibility and discrimination performances respectively – see Fig. 4 for a plot of the regression of position on the second MDS dimension against visibility). Interestingly, visibility seemed a better predictor. Thus, even though the two measures come from different groups of participants, the correlation suggest that the second perceptual dimension in metacontrast is tightly linked to visibility of the target.

3.2. Impact of instructions

The previous analyses were conducted on dissimilarities averaged over participants and instructions sets. Recall

² Two observers from the “focal” instructions sets made clear during debriefing that they did not perform the task and were excluded from all analyses.

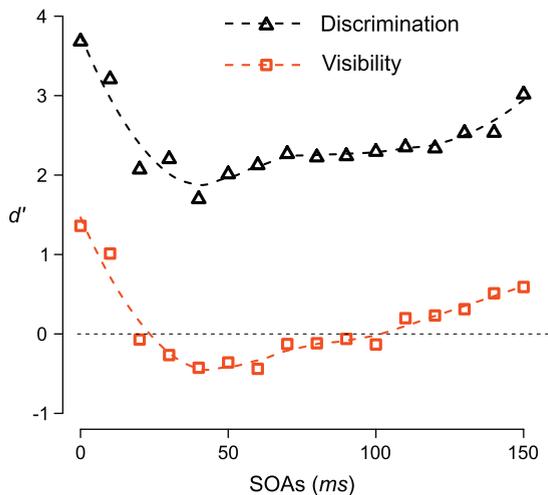


Fig. 3. Results for the discrimination/visibility experiment: d' transformed discrimination performances and visibility judgments are plotted against SOAs. Dotted lines are locally weighted scatterplot smoothing fits (LOESS, Cleveland, 1979). The minima are at 41 and 42.5 ms, and do not differ significantly ($p > .5$).

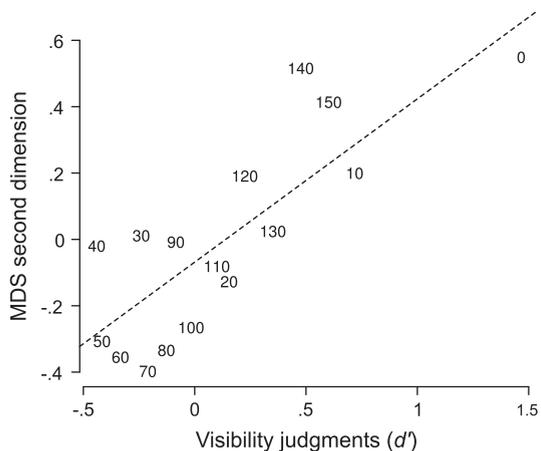


Fig. 4. For each SOA, position on the second dimension of the bidimensional MDS plotted against visibility (LOESS predictions of d' 's). Dotted line is the regression line. Recall that both measures come from different groups of participants. An analogous regression on discrimination performances is virtually identical and not shown.

however that some participants were requested to rate the similarity of the targets only in two target–mask pairs (“focal” group), while others had to rate the global similarity of the two pairs (“holistic” group) – see [Supplementary Fig. 1 online](#) for the MDS configurations of the two groups. In order to assess whether the perceptual spaces elicited by the two judgments were different, I used the INDSCAL individual differences model (Carroll & Chang, 1970; De Leeuw & Mair, 2009). This model takes as input one matrix of distances per participant, and finds a group configuration – accounting for individual differences by assuming that each participant is characterized by individual weights on each dimension. Thus, I computed the 2 and 3 dimensional INDSCAL solutions with the “holistic” and “focal” groups as

“individuals”. By construction the two configurations are in the same space, so that I could compute their overall distance as the sum of distances between homologous SOA points in the two configurations. I then compared this value to the distribution of the same statistic for 5000 bootstrap samples where each observer was randomly assigned to one or the other group. The actual sums of distance were at the .61 and .52 percentiles (in 2 and 3 dimensions respectively) of the bootstrap distributions, which strongly suggests that the two instructions sets elicited the same perceptual judgments. Thus, whatever the instructions, time and visibility are the two main dimensions of meta-contrast percepts. Accordingly, in subsequent analyses, instructions sets are not taken into account.³

3.3. Three dimensional analyses

Although this interpretation is appealing, there are hints that the story might be more complex. Indeed, as can be seen in the inset of [Fig. 2](#), there is a sharp drop in stress (the loss function in MDS, representing the amount of distortion introduced by the reduction of dimensionality) from the unidimensional to the bidimensional solution, but still the three dimensional solution seems to provide some improvement. Thus, I wanted to assess whether a higher dimensional MDS would yield informative results.

To this end, first, I computed a classic metric MDS on aggregated dissimilarity matrices with dimensionality = 2, ..., 5 and applied the jackknife procedure (de Leeuw & Meulman, 1986) as implemented in the SMACOF package (De Leeuw & Mair, 2009) in R. The value of the loss function was minimal for the 3 dimensions solution (8.227 as opposed to 9.482 and 11.64 for 2 and 4 dimensions) and the dispersion was also minimal for the 3 dimensions solution (.07 as opposed to .088 and .087), suggesting that the three dimensional solution was the most adequate. Second, I computed a matrix of the residuals for the two dimensional solution, as the difference, in each cell of the 16×16 matrix of similarities, between the observed dissimilarity and the dissimilarity in the MDS configuration. I reasoned that if the stress decrement in the three dimensional solution was simply due to the presence of an added parameter in the model, the residuals should only represent noise. Accordingly, the three dimensional solutions computed on the two dimensional solution augmented with random permutations of this noise should yield a comparable reduction of stress. However, quite the opposite happened: only 9.4% of the bootstrapped (5000 samples) distribution had smaller stress than the actual three dimensional solution.⁴ This indicates that the

³ As suggested by anonymous reviewers, it is also possible that naive observers did not follow the instructions in at least one condition. For instance they may have found the “focal” task too difficult and resorted to some version of the “holistic” task in its stead. In the [Supplementary materials online](#), I present some analyses, and results for one trained observer, that do not seem to vindicate this interpretation.

⁴ In order to deal with negative distances in the configuration + bootstrapped residuals matrices, I adopted the following very conservative approach: I considered all cases (9%) where the bootstrapped dissimilarity matrices had negative distances as having null stress.

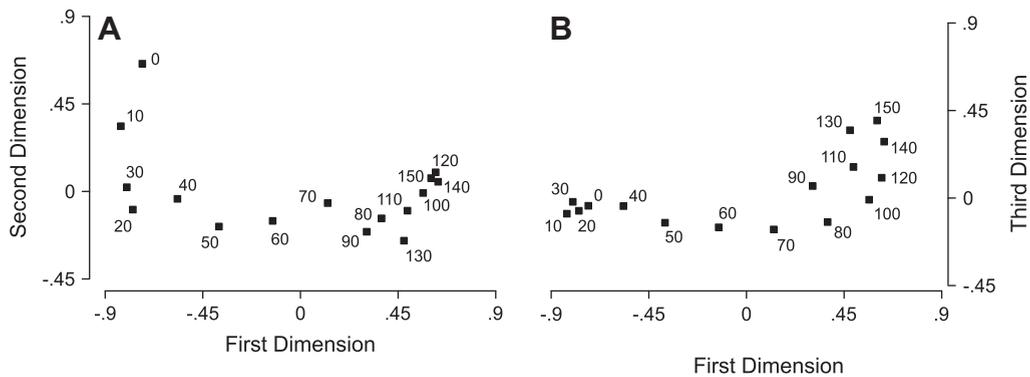


Fig. 5. Multidimensional scaling configurations for the 3 dimensions solution, computed with the INDSCAL model. Dimensions 2 (panel A) and 3 (panel B) are separately plotted against the first dimension. Numbers indicate SOAs.

matrix of residuals of the 2 dimensional solution does not represent random noise. Therefore, the 3 dimensional solution must reflect meaningful structure from participants' judgments. When applied to the three and four dimensional solutions, the same procedure yield strikingly different results, as the actual stress of the four dimensional solution was at the 88.2 percentile of the bootstrapped stress distribution. This analysis suggests that the reduction of stress from the three to the four dimensional solution is due to overfitting, while from two to three dimensions, it captures some structure of the data.

Hence, two methods pointed to the three dimensional solution as the most adequate. The three dimensional group configuration computed with the INDSCAL model is shown in Fig. 5A and B. As can be seen, the first dimension is again correlated with time, while the second and third dimensions correspond to the downward and upward branches of the U of the metacontrast function: short and intermediate SOAs are regularly spaced on the second dimension, while the third dimension discriminates among long SOAs. This suggests that, even though visibility may in some respect be equated across the trough of the metacontrast function, it still differs qualitatively between long and short SOAs.

4. Discussion

The following main results emerge from this first application of MDS to metacontrast: first, time is the most salient feature of the stimuli. The first dimension, both in the two and three dimensional solutions was an obvious monotonic function of the target–mask SOA, albeit compressed at the two ends. Importantly, even when observers were asked to focus only on the first visual event (the target) in the focal instructions set, their judgments still revealed a massive effect of the SOA.

It is difficult to ascertain here that the ordering of stimuli according to increasing SOAs corresponds indeed to any perceived duration. It might correlate with some visual property of the target or of the target–mask compound. However, notice that duration, being simply the SOA, is not confounded with visual energy, since the target and

the mask are themselves of fixed durations. Thus duration here is unlikely to give rise to contrast or form summation (Kahneman, 1966). Moreover, we know that observers are sensitive to the duration of visual events in the range of our stimuli (Allan, Kristofferson, & Wiens, 1971). Thus, the interpretation of the first dimension as expressing a perception of duration seems the most parsimonious. Since the durations of the target and the mask were fixed, it is impossible to tell whether the relevant physical parameter is the total duration of the stimuli, the SOA or some other variable (for instance the inter-stimulus interval).

That observers could not abstract from the duration dimension when requested to do so, may be interpreted as showing that at the timescale of metacontrast, the two physical events are perceptually yoked. In that sense, metacontrast stimuli form a single complex visual event. It is important to realize in this respect that roughly one half of the stimuli (SOAs below 80 ms) are within the range of visual integration times (Eriksen & Collins, 1967; Hogben & di Lollo, 1974; Cass & Alais, 2006; Forget, Buiatti, & Dehaene, 2010). Thus, results show that even within the range where observers do not fully dissociate the target from the mask, they are sensitive to some overall temporal property of the stimulus.

The second dimension of the perceptual space of metacontrast corresponds quite closely to the visibility of the target. This should not come as a surprise, as metacontrast is most often measured with, and used for, the decrement in visibility it produces. The lowest point on the second dimension corresponds to the minimum in visibility as measured with very similar stimuli. However, the main novel result is that visibility itself is not unitary. The U of the U-shaped metacontrast function is twisted, so that its descending and ascending branches do not lie in the same perceptual plane. High visibility as a result of short SOAs and as a result of long SOAs are perceptually distinct, as revealed by the three dimensional analysis. While in some sense visibility can be equated for short and long SOAs, these two classes of stimuli would still differ in perceptual quality: visibility under decreasing integration is perceptually distinct from visibility under increasing segregation.

Recent studies (Albrecht, Klapötke, & Mattler, 2010; Bachmann, 2009; Breitmeyer et al., 2006; Jannati & Di

Lollo, 2011) have revived the notion of “criterion content” (Kahneman, 1968), according to which observers faced with a metacontrast stimulus must choose the most appropriate perceptual criterion in order to perform the task. Quite often, when the targets and masks are integrated, at short SOAs, the resulting shapes do not look like the targets in isolation – cf (Jannati & Di Lollo, 2011) for a precise analysis of the popular “diamond”/“square” stimuli. Thus, the configural basis of the decision in a discrimination experiment might differ at long and short SOAs, yielding obvious differences in criterion content. However, whereas this might be the case for the discrimination/visibility experiment (at short SOAs, the main visible feature might be a triangular “hole” in the target + mask compound) it is less so with the stimuli I used in the main MDS experiment: as the targets are always plain squares with no intervening gap, figural (Gestalt) cues are constant across all SOAs – Notice that since masks are longer than targets, this is true even at SOA = 0 ms. Yet, the perceptual dimension for short SOAs stimuli differs from the perceptual dimension of long SOAs stimuli, even beyond the domain of temporal overlap between target and mask. In other words, short and long SOAs visibilities do not look the same, and if requested to make a visibility judgment on a unidimensional scale, participants would in all likelihood not use the same criterion content across the trough of the metacontrast function.

Although the methodology is novel, the results are in agreement with some data and theories of metacontrast. First, they are reminiscent of what (Bernstein et al., 1976) obtained by means of discriminant function analysis: the authors were able to conclude that *as far as brightness judgments were concerned*, participants employed distinct criterion contents at short and long SOAs. In effect, they could show that at short SOAs, subjects relied on a subtraction between the brightness of the stimulus and of the mask, whereas at long SOAs brightnesses would add up. It is important to note, however that my experiments do not focus only on criterion content for brightness judgments, but tries to map out more broadly the perceptual space of metacontrast.

Second, my results fit perfectly within the framework of the dual processes theory of metacontrast (Reeves, 1982). Such a framework hypothesizes that the U-shape of the metacontrast function derives from averaging across trial over two opposite monotonic stochastic processes: one decreasing “target–mask integration” process, and one increasing “target–mask segregation” process.⁵ (Reeves, 1982) conjoined, at the trial level, ordinal visibility judgments with binary simultaneity judgments, and was able to argue that the pattern of results did not favor a single-process account. My results also support a dual process account: the perceptual differentiation between the two branches of the metacontrast function can be construed as phenomenal counterpart to the two underlying processes. In further studies it should be possible to tighten the link between MDS approaches and the original methodology of

Reeves (1982) by also collecting simultaneity judgments or temporal estimations.

As noted above, 80 ms seems a critical time constant in the dynamic properties of vision (Eriksen & Collins, 1967; Hogben & di Lollo, 1974; Cass & Alais, 2006; Forget et al., 2010). It is noteworthy that the third perceptual dimension discriminates SOAs above 80 ms, suggesting that when the mask and the target cease to be fully integrated, observers start perceiving their increasing separation. However, I should here acknowledge that the results found in the present study are probably specific to the chosen shapes for the target and the mask. Indeed, (Duangudom, Francis, & Herzog, 2007; see also Francis & Cho, 2008) have shown that the shape of the metacontrast function, as estimated from a forced choice task, depended heavily on the particular shapes of both the target and the mask. Similarly, it is a well established fact (for a recent review, see for instance (Breitmeyer & Öğmen, 2006, pp. 48–50)) that the shape of the metacontrast function depends on the target/mask energy ratio. All of this should make it clear that the three dimensional analysis is most probably dependent on type B (U-shaped) metacontrast, which in turn depends on precise configural and energy conditions for both the mask and the target.

Garner (1974) urged that we should distinguish “integral” from “separable” dimensions in perception, according to the effort required to perceptually resolve them. The above results strongly suggest that time and visibility are *integral* dimensions of metacontrast percepts: First, observers were in fact never able to abstract the time dimension; second, visibility came in two guises that were tightly linked to distinct portions of the perceived duration dimension.

These results have some implications regarding the use of metacontrast in the study of visual awareness and its neural underpinnings. Metacontrast is perhaps a dead alley in the quest for an experimental paradigm designed to yield a control on pure visibility, for at least two reasons, in addition to the fact that “absolute” invisibility of the target is almost never achieved, except in specific paradigms (Otto et al., 2006): first, duration of the target–mask pair cannot be ignored by observers. Visible and invisible targets will always be embedded in time varying percepts. Second, and more importantly, if one wishes to abstract over performance differences by relying on divergent visibilities across the trough of the metacontrast function (“relative blindsight”, Lau & Passingham, 2006), one will in fact rely on very different percepts, one corresponding to an integrated target–mask pair, the other to a segregated pair.

Even phenomenologically inspired measures of visibility should be regarded with caution: indeed, measures such as the Perceptual Awareness Scale (PAS, Ramsøy & Overgaard, 2004; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010), which uses the four categories “No experience”, “Brief glimpse”, “Almost clear image”, “Absolutely clear image” are readily construed as ordinal scales. While observers might well be able to project, in a systematic fashion, their bidimensional visibility percept on a unidimensional scale, it should not obscure the fact that the dynamics of vision creates complex percepts whose

⁵ Note that (Reeves, 1982) also allows for a “no target” process, in order to account for trials where the target is invisible.

dimensions are probably very difficult to separate. In view of this result, it is certainly safer to construe visibility judgments as the resultant of a series of cognitive processes than as reports on an elementary perceptual quality.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.cognition.2012.09.013>.

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