Over-specification and uniform reduction of visual entropy facilitate referential processing

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Over-specifications (OS) are expressions that provide more information than minimally required for the identification of a referent, thereby violating Grice's 2nd Quantity Maxim [1]. In Figure 1, for example, the expression "Find the blue ball" identifies exactly one object in all panels, but only in the top displays is the adjective required to disambiguate the target. In recent years, psycholinguistic research has tried to test the empirical validity of Grice's Maxim, resulting in conflicting findings. That is, there is evidence both that OS hinders [2,3] and that it facilitates [4,5] referential processing. The current study investigates the influence of OS on visually-situated processing, when the context allows both a minimally-specified (MS) and an OS interpretation of pre-nominal adjectives (cf. Fig.1). Additionally, as the utterance unfolds over time, incoming words incrementally restrict the search space. In this sense, information on "blue" and "ball" is determined not only by their probability to occur in this context, but also by the amount of uncertainty about the target they reduce — in information theoretic terms [6]. A greater reduction of the referential set size on the adjective (A&C) results in a *more uniform* reduction profile (Uniform Reduction, UR), as the adjective reduces entropy by 1.58 bits and the noun by 1 bit. On the other hand, a moderate reduction of the set size on the adjective (B&D) results in a *less uniform* reduction profile (Non-uniform Reduction, NR): the adjective reduces entropy by .58 bits and the noun by 2 bits. This study examines whether, above and beyond any effects of specificity, the rate at which incoming words reduce visual entropy also affects referential processing.

Methods. We conducted an eye-tracking experiment crossing **Specificity** (MS vs. OS) and **Entropy Reduction** (UR vs. NR). Participants (N=24, mean age=25) were presented with displays such as the ones in Figure 1, and after 2sec heard an instruction in German to *Find the* ADJ TARGET, mentioning either the colour or pattern of the target object. Research on the production of OS has demonstrated that they are commonly used by adult speakers, both pre- and post-nominally [7,8,9], and with various types of adjectives [10]. As rational speakers would unlikely encode redundant information so consistently, if it hindered listeners' processing, we expected OS to be more or, at least, as beneficial as MS for referential processing, and, as found in [5], we expected to observe this effect on the noun. Regarding Entropy Reduction, either of two outcomes were expected: a) a preference for UR, indicating that expressions reducing *visual entropy* more uniformly across the utterance are more efficient for referential processing — consistent to the predictions of UID [11] — b) a facilitation for NR, suggesting that the *gradual restriction of referents*,

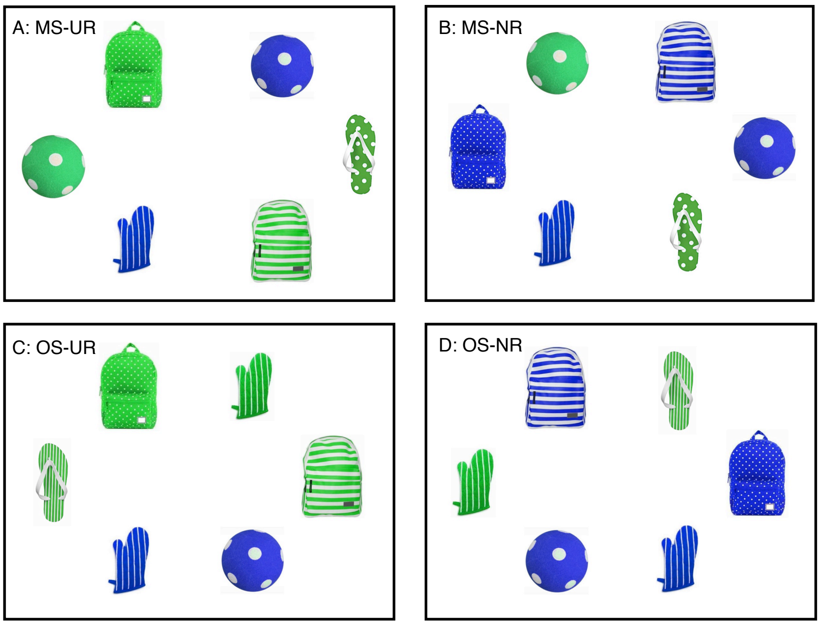

Figure 1. Sample visual stimuli, combined with the instruction "Find the blue ball".

rather than the rate of entropy reduction, facilitates processing. To examine these questions we compared inspection probabilities to objects of interest in the adjective and noun regions across conditions. As information about the target became incrementally available, different comparisons were interesting per region. On the adjective, since the target object was not yet known, we were interested in inspections to *single* (cf. the mitten in A&B, and the ball in C&D) and *contrast* (cf. the blue ball in A&B, and the blue mitten in C&D) objects in UR vs. NR. On the noun, we compared inspections to the *target* (the blue ball: MS in A&B, and OS in C&D) across conditions. In addition, we present results from the Index of Cognitive Activity (ICA), a novel measure of cognitive effort that is based on rapid pupil dilations that are due to load reflex, separating them from those due to light reflex or noise [12,13]. Higher ICA values are associated with greater cognitive workload. Finally, we also report Reaction Times across conditions.

Results. On the adjective, only one comparison yielded significant results, i.e. *contrast* objects were inspected more frequently in UR vs. NR.[1] On the noun, analyses of inspection probabilities to the *target* produced effects for colour items. Specifically, there was a marginal effect of Specificity, with more inspections in OS vs. MS (p=.06), suggesting a preference for OS. Furthermore, we observed a main effect of Entropy Reduction, with more inspections to the target in UR vs. NR (p=.048). Analyses of the ICA produced main effects of Entropy Reduction and Specificity for both colour and pattern items (cf. Fig.2), such that ICA values were lower for UR vs. NR (p=.003) and for OS vs. MS (p<.001). RTs also resulted in two main effects, with faster responses in UR vs. NR (p=.002) and OS vs. MS (p=.023).

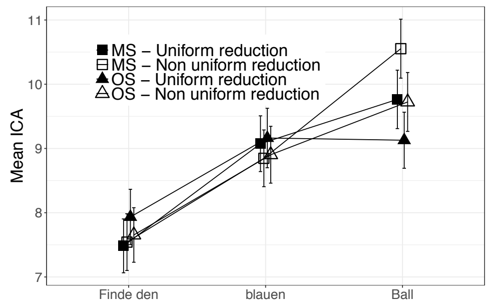

Figure 2. Mean ICA per condition and region. Error bars represent 95% CI.

Discussion. We present evidence confirming previous findings that redundant adjectives facilitate processing of the upcoming noun in situated comprehension [5]. Even though only colour items yielded higher inspection probabilities for OS vs. MS, ICA values and RTs were reduced also for pattern items, suggesting that, while pattern is less salient than colour, its mention is similarly beneficial. These results indicate a general advantage for OS in referential processing. In addition, we showed that uniform reduction of visual entropy, resulting from a more drastic decrease of referents on the adjective — while not accompanied by greater load in that region — is associated with a reduced cognitive effort when processing the noun. We entertain two explanations regarding the absence of an Entropy Reduction effect on the adjective. First, it may be that our manipulation of entropy reduction on the adjective was not that distinct between UR and NR. Secondly, it is possible that entropy reduction elicits end-state effects, showing up after the full entropy reduction profile of an utterance has evolved, and such effects cannot be observed "on the fly". We conclude that efficient processing is determined by both the degree of specificity of the reference, and its contribution to the uniform reduction of visual entropy across the utterance.

References. [1] Grice (1975) In Cole & Morgan. [2] Engelhardt et al (2011) *Brain Cogn* [3] Davies & Katsos (2013) *J pragmat* [4] Arts et al (2011) *J pragmat* [5] Tourtouri et al (2015) *CogSci* [6] Hale (2006) *Cognitive Sci* [7] Pechmann (1989) *Linguistics* [8] Engelhardt et al (2006) *JML* [9] Rubio-Fernández (2016) *Front Psychol* [10] Tarenskeen et al (2015) *Front Psychol* [11] Jeager (2010) *Cognitive Psychol* [12] Marshall (2000) US Patent 6,090,05 [13] Demberg & Sayeed (2016) *PLoS ONE*

[1] Since in NR more entities bear the mentioned feature (cf. the blue rucksacks in B&D), attention is spread across more objects. Therefore, we do not take this result to reflect any preference for a contrastive (MS) interpretation of the adjective.