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Letter to the Editor

Violations of Weber's law tell us more about methodological challenges in sensorimotor research than about the neural correlates of visual behaviour

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ABSTRACT

The violation of Weber's law in grasping has been presented as evidence for the claim that grasping is guided by visual information which is distinct from the information used in perceptual tasks. Previously, we contested this claim and argued that biomechanical constraints of the hand might explain why Weber's law cannot be reliably uncovered in grasping movements. In a recent article Manzone and colleagues (2017) show that pantomime grasping follows Weber's law even with objects whose width is close to the hand's biomechanical limit. In this commentary we explain why the biomechanical account does not necessarily predict the violation of Weber's law in a pantomime grasping task and why it seems problematic to use adherence or violation of Weber's law as a criterion to assign tasks to different anatomical pathways.

Psychology is not rich in scientific laws but Weber's law is one of them. Put simply, Weber's law states that the precision of our perceptual judgement decreases (or put differently the variability of that judgement increases) when the magnitude of the sensory attribute in question grows larger. As befits a law of nature, this principle was found to hold across a wide range of attributes, measurement procedures and sensory modalities (for reviews see: Billock & Tsou, 2011; Gescheider, 1997). Consequently this principle has been hailed as the starting point of modern scientific psychology (Boring, 1950; Krech & Crutchfield, 1958).

Almost 150 years after Gustav Fechner published his psychophysical principles including the Weber-Fechner law (Fechner, 1966/1860), Ganel and colleagues (Ganel, Chajut, & Algom, 2008) demonstrated a surprising violation of this law. They found that even though it is well established that grip size is linearly related to object size (for a review see: Smeets & Brenner, 1999); grip size variability does not increase with the size of objects to be grasped. Ganel, Chajut, and Algom (2008) argued that this finding reflects a fundamental difference in how visual information is processed for perception as compared to visually-guided action (e.g. grasping). This interpretation was motivated by the influential two-visual systems hypothesis (TVS, Milner & Goodale, 2006). The TVS-hypothesis proposes the existence of two visual systems: the ventral system which is responsible for visual perception and the dorsal system which is responsible for visually-guided action. Ganel et al.'s findings and interpretation received a mixed response. Smeets and Brenner (2008) argued that the finding was unsurprising as in their view (Smeets & Brenner, 1999) grasping is not based on the computation of object size but object position. Others embraced the idea that adherence or violation of Weber's law may provide a valuable marker for ventral versus dorsal-stream control of a given visual behaviour (e.g. Holmes & Heath, 2013).

To date, there is still a controversy about whether or not violations of Weber's law in grasping provide valuable insights into the neural control of visually-guided behaviour. But which side has the better arguments? Let us remind ourselves that Weber's law has been hailed as one of the most reliable principles in the domain of Psychology, the day of its publication has been called the birthday of modern Psychology. Violations of Weber's law in experimental data have often been reported and often been resolved. For example, it has been argued that violations of Weber' law in vision can be traced to conditions which engender cross-channel interactions and incomplete adaptation, and can be avoided by enforcing complete adaptation during the experiment (Kulikowski & Gorea, 1978). Given this history any new report of a violation of Weber's law should be treated with interest but also with some scepticism.

In a recent paper published in this journal, we proposed a potential artefact that might account for the violation of Weber's law in grasping (Utz, Hesse, Aschenneller, & Schenk, 2015). When grasping an object there is a natural upper limit to the maximum opening of the hand. Naturally, the hand cannot be opened wider than allowed by the span of the individual's hand. While the span of the hand provides a hard biomechanical limit, there is in fact an earlier soft limit. For most actions we prefer movements that are within the mid-range of each joint's movement range. Full flexions or extensions are typically avoided and are experienced as uncomfortable. Models of motor control assume that comfort is an important soft constraint which is used alongside energy- and error-minimization to select and determine the optimal motor parameters for a planned action (Rosenbaum, Meulenbroek, Jansen, & Vaughan, 1998). Furthermore, a number of additional factors have to be considered during grasping. The hand needs to open wide enough to ensure that the fingers will clear the edges of the object, in fact the opening must be a good deal wider to ensure that the fingers will approach the object's grip surface from an angle that is roughly orthogonal to the orientation of that surface (Smeets & Brenner, 1999). This explains why in grasping the maximum hand opening (commonly referred to as the maximum grip aperture, MGA) is typically larger than the target's width. This ratio varies between 1.3 and 3.3 (see Smeets & Brenner, 1999 for review,). In our study that ratio was approximately 1.9 – a comparatively high ratio that might reflect an increased safety margin induced by the participants' unfamiliarity with the mirror setup used in our study. The difference between the required opening, corresponding to the target's width, and the actual maximum hand opening during the movement, is called the safety margin. The safety margin varies between studies. In the review by Smeets and Brenner (1999) values between 20 and

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80 mm can be found. Balancing the need for a safety margin with the aim to perform comfortable and efficient movements will typically lead to a tendency of having larger safety margins for smaller objects than for larger objects. This tendency is reflected in the slope of the linear function relating object size to MGA. In the majority of grasping studies this slope is somewhere between 0.7 and 0.9 (see Smeets & Brenner, 1999, Fig. 7). A slope below 1 (i.e. reflecting the case that an increase in 1 cm in object size results in an increase of less than 1 cm in MGA) means that the safety margin is larger for smaller as compared to bigger objects. As a consequence, one source of variability inherent in the grip size (or more precisely MGA) variability, namely the variability in the safety margin, will decrease with increasing target size. This trend runs directly counter to the trend expected on the basis of Weber's law, and might therefore cause grip size variability to remain constant or even decrease with increasing target size. We found such a reversed trend for four out of six grasping tasks that we tested, and concluded that the apparent violation of Weber' law in grasping is likely to be caused by the biomechanical limits of the human hand and thus is not indicative of a true violation of Weber's law (Utz et al., 2015).

Manzone and colleagues (Manzone, Davarpanah Jazi, Whitwell, & Heath, 2017) examined whether the biomechanical account applies also to a pantomime grasping task. The pantomime grasping task was demonstrated by Goodale, Jakobson, and Keillor (1994) to be affected by ventral stream damage. It is assumed that pantomime grasping is a communicative gesture and not a goal-oriented action. Hence, it falls outside the category of visuomotor behaviours served by the dorsal stream and within the category of visual behaviours that fall under the purview of the ventral stream (but see Schenk, 2012a; Schenk, 2012b for a different account of why pantomime grasping might be reliant on ventral stream input). Pantomime grasping thus provides an interesting test case to pit the predictions derived from the TVS hypothesis against those derived from the biomechanical account. The TVS hypothesis predicts that pantomime grasping is mediated by ventral stream processing and will, thus, adhere to Weber's law. In contrast, the biomechanical account seems to suggest that with sufficiently large target objects Weber's law will also be violated in the case of pantomime grasping. Manzone and colleagues examined pantomime grasping with target objects ranging from small objects (10% of participants' maximum hand separation span – about 15–20 mm) to fairly large objects (80% of participants' maximum hand separation span – about 105–120 mm). Just Noticeable Differences (JNDs), defined as the within-participant standard deviation in MGAs, increased significantly with target object size, thus indicating that pantomime grasping adheres to Weber's law. This finding seems to undermine the biomechanical account, and to support the hypothesis that pantomime grasping is mediated by ventral stream input. Consequently, the study vindicates Weber's law as a reliable criterion to determine whether the visual input for a given task originates from the ventral or dorsal visual system. In the following paragraphs we wish to explain why Manzone et al.'s finding might not be as critical for the biomechanical account as it appears and why we still doubt that using Weber's law provides a useful tool to assign behavioural tasks to visual systems.

An important difference between the grasping performance reported by Utz et al. (2015) and Manzone et al. relates to the safety margin. Utz and colleagues reported an average safety margin of approximately 40 mm while the corresponding value for Manzone et al.'s study was less than zero, i.e. the MGA in the Manzone et al. study was on average smaller than the actual width of the target object. To explain this finding Manzone and colleagues pointed to the fact that in their study no physical object was present at the location of the grasp. This means, there was no need to establish a firm grip on the object, no need to avoid collisions between fingers and object during the grasp, no need for a grip-surface orthogonal approach vector and thus no need for a safety margin. In addition, vision of the hand was available in Manzone et al.'s study but not in the study by Utz and colleagues. This may have further contributed to the difference in safety-margin sizes found between the two studies, as it is well known that withdrawal of hand-vision increases the safety margin (e.g. Churchill, Hopkins, Roenqvist, & Vogt, 2000). Irrespective of those considerations, the fact remains that safety margins were absent during grasping in Manzone et al.'s study. We would argue that with biomechanical factors acting as soft – but not hard- constraints (except in cases in which the width of the target object equals or exceeds the hand span), their main influence will be seen on the aspect of the MGA which is not directly determined by the width of the target object, i.e. the safety margin. Furthermore, with a safety margin of 40 mm, MGAs in the study by Utz et al. were for the same object size closer to the functional limit of the participants' hands and thus presumably more strongly affected by the participants' biomechanical limits than the MGAs in Manzone et al.'s study. Thus, given the relationship between open-loop grasping and safety margins, it seems likely that biomechanical limits play a more pronounced role in open-loop grasping. In sum, the absence of a safety margin in Manzone et al.'s study could explain why they did not observe a limiting effect of participants' functional grasping range.

This discussion of the varying relevance of biomechanical limits in different types of grasping movements brings us to a more general issue. Can we actually consider MGAs as reliable read-outs of the representation of an object's size in the dorsal system? Treating MGAs as a read-out of object-size as represented in the dorsal stream is an assumption frequently used in perception-action studies but rarely stated or examined. In our view it is a problematic assumption (see also Hesse, Miller, & Buckingham, 2016 for a similar argument). An optimal grasp is typically not defined by a good match between MGA and target width; it is defined by a secure and stable grip, a fluid movement and an efficient use of forces and energy. The correlation between MGA and target width is thus an emergent feature, not the primary goal of the action. This means grasping kinematics, including the MGA, are shaped by many factors in addition to the object's size. Importantly, the relevance and contribution of these factors will vary from task to task and the reliability of MGAs as estimates of target-width will change accordingly. In a pantomime grasp, grip force, the angle of approach, and safety margins do not matter and thus MGAs are likely to be closely correlated with veridical object-width. Variability in MGAs may therefore also correlate with variability in perceptual estimates of the target width. These size-estimates are assumed to adhere to Weber's law. Consequently, Weber's law may prevail in pantomime grasping. However, in most other grasping tasks, additional factors will determine MGA and may mask the Weber-law like relationship between MGAs and target widths.

This contrast between pantomime grasping and other forms of grasping is in our view quite instructive as it highlights a more general asymmetry between so-called perceptual and visuomotor tasks. In support of the TVS-hypothesis a number of perception-action task-pairs have been employed. Such pairs have in common that they presumably exploit the same visual feature but use different behavioural responses, namely a perceptual report versus a manual action. Apart from manual estimation versus grasping, another classic example is orientation matching versus posting. It is assumed that in both cases the alignment of the card's orientation with the orientation of a slot is the key feature guiding the tasks. However, we have shown that while the width of the slot has no effect on the matching task it significantly affects posting performance indicating that participants use different features and strategies to perform the two tasks (Hesse, Franz, & Schenk, 2011). Another example comes from the comparison between line-bisecting performance (the presumed perceptual task) and obstacle avoidance (the presumed visuomotor task). Again it is assumed that in both cases the computation of the midpoint between the two obstacle positions is the key feature guiding performance in both tasks. Yet again we found a factor, namely the start position of the hand, which only has a substantial effect on obstacle avoidance but not on bisecting performance (Ross, Schenk, & Hesse, 2014). It is thus neither new nor unexpected that when comparing pantomime grasping with grasping there are also factors, such as biomechanical constraints, which have no or little effect on pantomime grasping but considerable effects on real grasping.

In addition, there are other reasons why it might be premature for us to abandon the biomechanical hypothesis. This hypothesis can actually