

1 Title:

2 ***Object visibility, not energy expenditure, accounts for spatial biases in human***
3 ***grasp selection***

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17 Author Contributions:

18 GM, VCP, LKK and RWF conceived and designed the study. VP collected the data. GM and VP
19 analyzed the data. All authors wrote the manuscript.

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21 **Abstract**

22 Humans exhibit spatial biases when grasping objects. These biases may be due to actors attempting to
23 shorten their reaching movements and therefore minimize energy expenditures. An alternative
24 explanation could be that they arise from actors attempting to minimize the portion of a grasped object
25 occluded from view by the hand. We re-analyze data from a recent study, in which a key condition
26 decouples these two competing hypotheses. The analysis reveals that object visibility, not energy
27 expenditure, most likely accounts for spatial biases observed in human grasping.

28 **Keywords:**

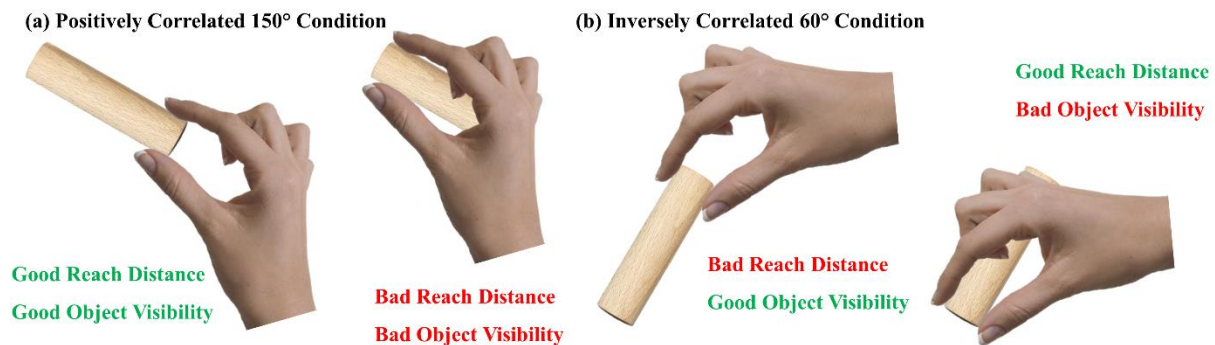
29 Precision grip | Movement distance | Minimum energy | Object visibility | Perception/action |
30 Reaching/grasping | Visuo-haptic interactions

31 **Main Text**

32 Human grasp selection is influenced by an array of factors, including the size, shape, mass, material,
33 orientation, and position of the grasped object (e.g. see Cesari & Newell, 1999; Paulignan, Frak, Toni, &
34 Jeannerod, 1997; Paulun, Gegenfurtner, Goodale, & Fleming, 2016; Schot, Brenner, & Smeets, 2010).
35 Additionally, it has been proposed that humans may attempt to perform grasping movements
36 economically, i.e., by minimizing the amount of work and resulting energy expenditure (Huang, Kram, &
37 Ahmed, 2012). Minimizing energy expenditures could therefore explain spatial biases in grasping
38 patterns, such as the biases toward shorter movement distances observed in several studies (Desanghere &
39 Marotta, 2015; Glowania, van Dam, Brenner, & Plaisier, 2017; Kleinholdermann, Franz, & Gegenfurtner,
40 2013). However, a study by Paulun, Kleinholdermann, Gegenfurtner, Smeets, & Brenner (2014)
41 questions this hypothesis. Participants were asked to grasp objects while approaching them from different
42 sides. Contrary to the expectation that participants should be biased toward shorter reaching movements
43 regardless of the side of approach, the authors found that participants grasped the right side of the objects
44 irrespective of where the movement started when grasping with the right hand. The authors concluded
45 that participants simply preferred grasping objects on the side of the acting hand, and suggested that this
46 behavior may help increase the visibility of the objects during grasping and subsequent manipulation
47 (Bozzacchi, Brenner, Smeets, Volcic, & Domini, 2018).

48
49 A more recent study by Paulun et al. (2016), which investigated how material properties and object
50 orientation affect grasping, serendipitously contained two experimental conditions that can be used to
51 contrast the object visibility hypothesis against the minimum reach hypothesis (Figure 1). Participants
52 were asked to grasp, with a precision grip, small cylinders of Styrofoam, beech wood, brass and Vaseline-

53 covered brass presented at different orientations. In the 150-degree rotation condition (Figure 1a),
54 grasping the object on its right side would result in shorter reach movements as well as increased object
55 visibility, whereas grasping the object on its left side would result in longer reach movements as well as
56 decreased object visibility: here the object visibility and minimum reach hypotheses make positively
57 correlated predictions. The two hypotheses make inversely correlated predictions in the 60-degree
58 rotation condition (Figure 1b). Here, grasping the object on its right side would result in longer reach
59 movements but increased object visibility, whereas grasping the object on its left side would result in
60 shorter reach movements but decreased object visibility.



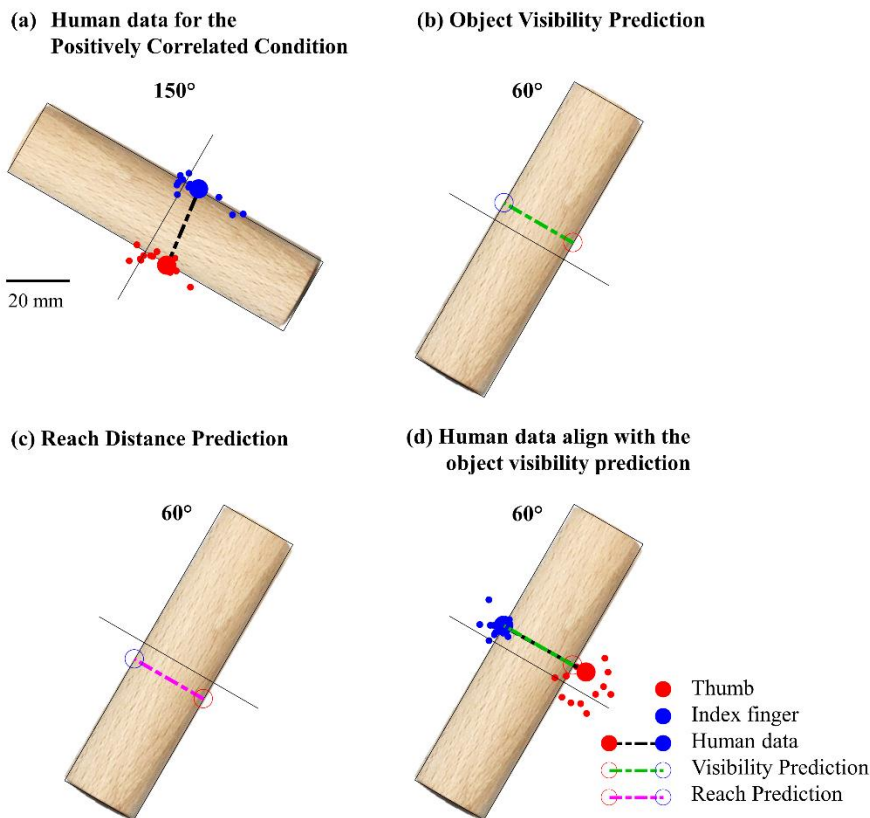
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62 *Figure 1. Two conditions from Paulun et al. (2016) that contrast the object visibility and minimum reach hypotheses*
63 *against each other.*

64 We therefore reanalyzed the data from these two conditions from Paulun et al. (2016) to distinguish
65 whether participants (N=14) exhibited grasping behavior consistent with the minimum reach or the object
66 visibility hypotheses. In Paulun et al. (2016) stimuli were placed 36 cm in front of participants. Each trial,
67 participants positioned their right hand at a start location on the right (36 cm away from the center).
68 Following an auditory cue, participants grasped the stimulus object with a precision grip, lifted it, and
69 transported it to an elevated goal position 28.5 cm to the right. The position of the tips of the thumb and
70 index finger were recorded using an Optotrak 3020, the position of the fingertips at the moment of first
71 contact were determined using the methods adapted by Schot, Brenner, & Smeets (2010b). Participants
72 executed 5 trial repetitions for each condition (4 materials x 6 orientations; here we only consider the 150-
73 deg and 60-deg orientation conditions).

74 In our reanalysis for both the 150-deg and 60-deg conditions, we first computed the medoid grasp for
75 each participant across object materials and trial repetitions (i.e. 20 trials per observers and orientation),
76 and then we computed the medoid grasp across participants. The medoid (a concept similar to the mean)
77 is the element of a set that minimizes its distance to all other elements. We excluded from the analysis the
78 4% of grasps that fell along the long axis of the objects. First, we looked at the medoid grasp pattern in

79 the 150-degree rotation condition and confirmed that the medoid grasp across participants was biased to
80 the right side of the object (Figure 2a). We quantified the bias as the mean deviation of the grasp center
81 (average between thumb and index finger) from the object midline. Next, we used the bias in the 150-deg
82 condition to make predictions regarding what the bias should be in the 60-deg condition under the two
83 competing hypotheses. Additionally, we made the simplifying assumptions that grasps should be
84 perpendicular to and in contact with the surface of the object. Thus, in the 60-deg condition, if
85 participants were attempting to increase object visibility, they should exhibit a similarly-sized bias for
86 grasps above the object midline (Figure 2b). If, on the other hand, participants were attempting to
87 minimize reach distance (and therefore energy expenditures), grasps should be biased by the same amount
88 to the region below the object midline (Figure 2b). Figure 2d shows how the medoid grasp across
89 participants and conditions is indeed shifted above the object midline, contrary to the minimum reach
90 hypothesis, and in near perfect alignment with the object visibility hypothesis. This observation is
91 confirmed by a simple statistical test: the average grasp distance to the object visibility prediction, across
92 participants, is significantly smaller than the average grasp distance to the minimum reach prediction
93 ($t(13)=5.66$, $p=7.8*10^{-5}$, paired samples t-test).



95 *Figure 2. Human grasps compared to the two competing hypotheses. Small markers represent human medoid grasps*
96 *for each participant across object materials and trial repetitions. Large markers are the medoid grasp across*
97 *participants.*

98 Our observation therefore suggests that humans are not attempting to minimize energy expenditures when
99 selecting where to grasp an object, at least not through minimizing reach distance. Instead, the observed
100 spatial biases for which participants tend to grasp objects on the side of the acting hand are consistent
101 with the hypothesis that humans are attempting to minimize the portions of the objects occluded by the
102 hand. Energy minimization principles may still play a role in the planning and on-line control of arm and
103 hand movements during grasping (e.g. Soechting, Buneo, Herrmann, & Flanders, 1995). However, in the
104 situations in which spatial biases in grasping are typically observed (Desanghere & Marotta, 2015;
105 Glowania et al., 2017; Kleinhodermann et al., 2013), these biases are likely too small to induce
106 noticeably different energy costs. Therefore, object visibility, not energy expenditure, accounts for these
107 spatial biases in human grasp selection.

108 **Data availability.** Data and analysis scripts will be made available from the Zenodo database.

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