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The role of effect grouping in free-choice response selection

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ABSTRACT

Which motor actions are preferred to replace an initially planned but momentary not executable action? Previous research (Khan, Mourton, Buckolz, Adams, & Hayes, 2010, Acta Psychologica) suggests that anatomical constraints seem to be a major determinant for such choices: For example, participants more frequently chose to respond with the finger homologous to the prepared one. We argue that in this case finger homology is confounded with action effect similarity, and action effects have been ascribed a crucial role in action selection. We report two experiments. Experiment 1 replicated the results obtained by Khan et al. In Experiment 2, we introduced visual action effects in the paradigm. Results from this experiment clearly point to a role of effect similarity in addition to mere finger homology status for the choice frequency effect.

1. Introduction

Imagine you're preparing to hit the gas pedal of your car. While doing so, an unexpected event happens—a soccer ball is kicked on the road—and you must abort the initial plan and now hit the brake pedal instead. This is just one example of a situation demanding a change of an initial action plan in order to successfully accommodate to current environmental demands.

There is much evidence that knowledge about upcoming events improves performance because attention can be directed toward a particular location or item, both externally in the environment (e.g., Posner, 1980) and internally in memory (e.g., Griffin & Nobre, 2003; Janczyk & Berryhill, 2014). Pre-specifying characteristics of a to-be-produced movement also facilitates its initiation (e.g., Rosenbaum, 1980). It is further assumed that several possible responses are grouped together and that preparation for one element of such a subgroup brings about facilitated responding if another element of the same subgroup is to be executed eventually because otherwise the existing subgroup must be overcome (Adam, Hommel, & Umiltà, 2003; Miller, 1982). From such studies, it can be concluded that switching from one to another action benefits from pre-activation or subgroup membership. However, in many situations—such as in our introductory example—the new action is not prescribed but must rather be selected from several alternatives. The fictive driver may as well have turned the steering wheel appropriately to avoid hitting the soccer ball (instead of braking).

Tasks in which participants are to freely choose from several behavioral alternatives are technically termed *free-choice* tasks (Berlyne, 1957) in comparison to *forced-choice* tasks, where a stimulus entirely determines the one and only correct response (see also Janczyk, Dambacher, Bieleke, & Gollwitzer, 2014). Of crucial interest in such free-choice tasks is the question, "Which alternative is finally chosen?" There is evidence that subtle environmental events happen to influence the choice. For example, in one study, participants were to freely choose and articulate digits ranging from 1 to 9. Shortly preceding, they experienced short/long and quiet/loud tones, and in general, higher digits were chosen following intense tones (Heinemann, Pfister, & Janczyk, 2013). Even subliminally presented (arrow) cues seem to reliably influence participants' behavior in a free-choice task briefly after the cue (Kiesel et al., 2006; Schlaghecken & Eimer, 2004).

Further, the anatomical status of the relevant effector appears to influence choices. This was shown with an elegant paradigm by Khan, Mourton, Buckolz, Adam, and Hayes (2010), and their Experiment 1 is of particular relevance for the present purpose. In this experiment, four responses were possible. Thus, the right and left index and middle fingers were placed on the F, G, J, and K key of a computer keyboard. Four spatially corresponding rectangular visual boxes were presented in a row on a computer screen. A pre-cue (color change of one of the rectangles) indicated one particular response, which was to be prepared

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by the participants. Briefly thereafter, a left/right-pointing arrow appeared between the two central stimuli and pointed to either the two left or the two right boxes. This was the imperative stimulus, and two conditions were distinguished: If the arrow pointed toward the cued location, a forced-choice trial, the prepared response was to be executed. If the arrow pointed toward the opposite direction, participants were to choose freely from the two response alternatives on that side, thus a free-choice trial. The crucial finding was that participants more often chose to respond with the finger that was homologous to the prepared finger (i.e., if a response with the left index finger was prepared, a right index finger response was produced in a free-choice trial more likely than was a right middle finger response). This advantage was absent in other blocks, where participants were not to prepare the cued response but rather to prevent/inhibit execution of this particular response in a forced-choice trial. These results were interpreted in terms of the Grouping Model (Adam et al., 2003), which assumes that performance in response-cueing tasks is facilitated by processes of subgroup building in perceptual-motor representational space. Such subgroups are mostly specified by low-level operations based on, for example, Gestalt principles like symmetry or proximity. Accordingly, preparation of one response (automatically) resulted in the formation of subgroups, for example, that of homologous fingers (symmetry). Because the homologous finger was then a member of the same subgroup, the probability of its initiation was enhanced.

In the following, we suggest that mere finger homology, although certainly important, was not the sole reason for this observation. According to ideomotor approaches to action control (e.g., Harleß, 1861; James, 1890; see Pfister & Janczyk, 2012, and Stock & Stock, 2004, for historical remarks) and its modern descendants such as the Theory of Event Coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001), individual motor actions cannot be accessed directly, but only by retrieving memories of their sensorial consequences: their action effects. Action effects can be either environment-related (such as a light or a tone) or body-related (such as the proprioceptive feedback from bending a finger and feeling the touch of the response key).[1] Evidence for this assumption comes from response–effect compatibility experiments. For example, left/right responses are produced faster if predictably followed by spatially compatible left/right visual effects than when predictably followed by spatially incompatible right/left visual effects (Kunde, 2001). This basic principle does not only hold for simple key press responses but also for continuous left/right movements (Janczyk, Pfister, & Kunde, 2012; Kunde, Pfister & Janczyk, 2012), wheel rotations (Janczyk, Pfister, Crognale, & Kunde, 2012), scrolling directions in human–computer interaction (Chen & Proctor, 2013), and also for rather abstract relations such as the verbal production of a number that is followed by the visual presentation of the same or another number (Badet, Koch, & Toussaint, 2013; for a recent review, see Shin, Proctor, & Capaldi, 2010). The problem is that it is conceivably hard to experimentally manipulate body-related action effects. One recent study with tactile action effects reported the same result patterns as was previously observed for environment-related action effects (Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014). Nonetheless, the employed manipulation was at best an approximation of “true” body-related action effects. The typical way to disentangle the role of responses/anatomical features and action effects is thus to add (visual) environment-related action effects to the responses and to vary their compatibility (see also Janczyk, Pfister, Hommel, & Kunde, 2014).

One study applied this logic to bimanual key pressing (Janczyk, Skirde, Weigelt, & Kunde, 2009). It was argued that the well-known advantage of responding with two homologous fingers simultaneously (e.g., Cohen, 1971) does not only imply the use of homologous fingers (thus an anatomical constraint) but also comes with perceptual symmetry as a result. Perceptual symmetry, in turn, is known to improve performance (e.g., Mechsner, Kerzel, Knoblich, & Prinz, 2001; Mechsner & Knoblich, 2004). Also, pressing keys simultaneously with homologous fingers requires anticipation of two rather similar body-related action effects to bring about the overt movement (as compared to non-homologous fingers requiring anticipation of rather distinct body-related effects). Thus, Janczyk et al. (Experiment 1) coupled visual effects (growing columns) with four response keys operated with the left and right index and middle fingers. For one group, using homologous fingers resulted in similar visual effects (and thus non-homologous fingers resulted in different visual effects). This group showed the typical advantage of homologous fingers (that was confounded with the production of similar visual effects). In another group, the relationship between finger homology and effect-similarity was reversed, and this yielded faster responses with non-homologous fingers (that resulted in similar visual effects) than with homologous fingers (resulting in different visual effects). Thus, important in this experiment was the production of similar effects that led to faster responses, regardless of the finger homology status. In sum, it can be argued that participants in the Khan et al. (2010) study did not actually choose the homologous finger but rather that particular response that gives rise to a similar (body-related) action effect as the cued and prepared response does.

There is indeed evidence for a role of action effects when a switch from a prepared to another action is required (Kunde, Hoffmann, & Zellmann, 2002). Participants can switch more quickly from an initially cued to an actually required motor action, if prepared and actually required action would predictably produce the same rather than different auditory effects. This observation suggests a crucial role of the similarity of action effects for response re-programming. Whether this observation extends to choice frequency in a free-choice task remains unknown but certainly possible against the background of the above reviewed studies.

We report two experiments. Experiment 1 was closely modeled after the first experiment in the Khan et al. (2010) study and—to anticipate—we were successful in replicating the higher frequency of homologous finger choices when participants were instructed to prepare a particular response at the outset of a trial. Experiment 2 built upon these results and tested an impact of action effects beyond mere finger homology status. To this end, each response key was coupled with visual action effects (growing columns as used by Janczyk et al., 2009).

2. Experiment 1

This experiment was a close replication of Khan et al.'s (2010) Experiment 1. Participants were presented with a cue signaling a to-be-prepared response. Upon presentation of an arrow stimulus, a forced- or a free-choice situation arose. Our focus was on the free-choice situation, where participants were to choose and press one of the two possible response keys of the other hand. Against the background of the Khan et al. study, we expected a higher frequency of homologous finger choices.

2.1. Methods

2.1.1. Participants

Sixteen undergraduate students participated for course credit (12 females; mean age = 23.5 years). All participants gave consent prior to experimentation and were naïve regarding the hypotheses of the experiment. One participant exclusively chose the homologous finger in free-choice trials and was thus excluded from analyses.

2.1.2. Apparatus, stimuli, and procedure

Experimental protocols were controlled by a standard PC. Stimuli were presented on a 17-in. CRT screen, and responses were collected via a QWERTZ keyboard using the keys F, G, J, and K. Each trial began with the presentation of four black squares with white outline (2000

[1] James (1890) used the terms “remote” and “resident” effects to refer to these different types of effects.

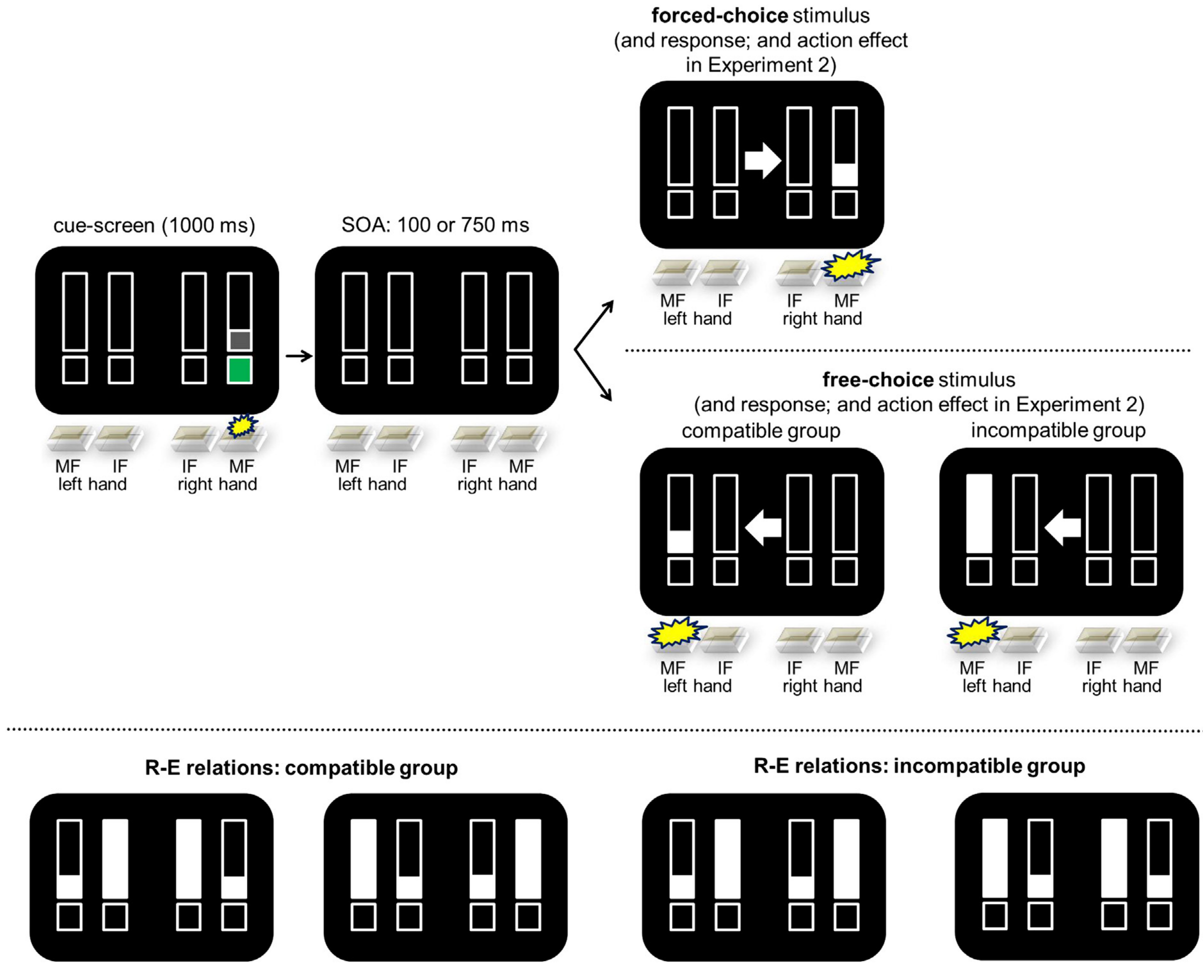

Fig. 1. Upper panel: illustration of trials. The green rectangle (cue-screen) indicates which response is to be prepared by the participants. (In Experiment 2, pressing this key would result in a visual action effect indicated by the dark gray color in the rectangle above.) In forced-choice trials, the arrow stimulus points toward the cued stimulus/response (in go-to blocks; in no-go-to blocks, the other key of the same hand was to be pressed). In free-choice trials, the arrow stimulus pointed toward the opposite side. In this case, participants were to choose from the two alternative responses of the other hand (in the figure, the homologous response is chosen). In Experiment 2, the key press (in both forced- and free-choice trials) resulted in a visual action effect. (Note: The rectangles above the stimulus squares and the corresponding action effects appeared only in Experiment 2. The mapping of response keys to action effects [low or high growing columns] divided participants into a "compatible" and an "incompatible" group; see text for more explanation.) Lower panel: illustration of the possible response–effect (R-E) relations in Experiment 2. For the compatible group, homologous fingers were coupled with similar effects; for the incompatible group, they were coupled with different effects. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

ms; see Fig. 1 [upper panel] for an illustration). One square changed its color to green (1000 ms; the cue), and following an SOA of 100 or 750 ms, the imperative stimulus set on, an arrow pointing to the left or right, until a response was produced. Participants were instructed to prepare pressing the response key corresponding to the cue. Depending on the arrow's direction, two trial types can be distinguished: A *forced-choice* trial occurred if the arrow pointed into the direction of the cue. Depending on the current block (see below), the participant either was to press the cued response key (go-to block) or the other response key of the same hand (no-go-to block). If the stimulus pointed to the not-cued side, this was a *free-choice* trial. In this case, participants were to freely choose from the two possible response keys on that side.

Each participant performed in four blocks, with either Blocks 1 and 2 being go-to blocks and Blocks 3 and 4 being no-go-to blocks or vice versa (counterbalanced across participants). Blocks 1 and 3 were unanalyzed blocks of 20 random trials to familiarize participants with the task. Blocks 2 and 4 had 160 trials, resulting from 10 repetitions of 4 cue positions × 2 SOAs × 2 trial types.

2.1.3. Data treatment and analyses

Trials with errors were excluded prior to the following analyses. The main analyses focused on the percentages of homologous finger choices in free-choice trials. These percentages were calculated for each participant separately for go-to and no-go-to blocks and were compared with a paired-samples t-test and additionally tested against a fixed value of 50% with one-sample t-tests. RTs were analyzed with an analysis of variance (ANOVA) with block (go-to vs. no-go-to) and trial type (forced-choice vs. free-choice: homologous vs. free-choice: non-homologous) as repeated measures. RTs were eliminated if they deviated from the mean by more than 2.5 SDs calculated separately for each participant and design cell (2.9% of the trials). Error percentages were analyzed with an ANOVA with trial type (forced-choice vs. free-choice) and block (go-to vs. no-go-to) as repeated measures.

2.2. Results

In go-to blocks, participants chose the homologous finger in 58.9% of the trials. This value is significantly different from 50%,

Table 1
Mean correct RTs [ms] in Experiment 1 as a function of trial type and block.

Trial type	Go-to blocks	No-go-to blocks
Forced-choice	546	639
Free-choice: homologous	715	702
Free-choice: non-homologous	712	664

$t(14) = 2.55$, $p = .023$. In contrast, in no-go-to blocks, the corresponding value was 49.0% which was not significantly different from 50%, $t(14) = 0.47$, $p = .646$. Most importantly, the observed percentages differed significantly from each other, $t(14) = 2.35$, $p = .034$.

The analysis of mean correct RTs (see Table 1) revealed a significant main effect of trial type, $F(1,14) = 5.58$, $p = .009$, $\eta_p^2 = .29$, and a significant interaction of trial type and block, $F(1,14) = 7.39$, $p = .003$, $\eta_p^2 = .35$. RTs were faster for forced-choice than for free-choice trials, but this was particularly pronounced in go-to blocks where forced-choice RTs were more than 150 ms faster than free-choice RTs. The main effect of block was not significant, $F(1,14) = 0.09$, $p = .771$, $\eta_p^2 = .01$.

Participants made errors in 3.7% and 8.6% (go-to- and no-go-to blocks, respectively) of the free-choice trials and 10.4% and 5.4% of the forced-choice trials. No effect reached significance, all $F\text{s} \leq 2.98$, all $p\text{s} \geq .106$.

2.3. Discussion

The critical results of this experiment were similar to those observed in Experiment 1 of Khan et al. (2010). First, a higher frequency of homologous finger choices was observed in go-to blocks (to a similar degree as in the original experiment). Second, and also replicating the earlier results, this effect was absent in no-go-to blocks. Third, responses were produced much faster on forced-choice trials than on free-choice trials, suggesting that participants did not explicitly prepare the homologous finger as well. If they did so, this would have suggested a strategic subgroup creation and perhaps explain the higher choice frequency. Experiment 2 will explore whether action effects do play a role for the choice frequency effect beyond the mere finger homology status.

3. Experiment 2

In Experiment 2, each response key was coupled with a visual effect, a growing column as used previously by Janczyk et al. (2009). For one group, selecting and depressing the homologous finger in free-choice trials resulted in a similar visual effect that would have resulted from responding with the cued finger (we call this group “compatible”). The performance of this group was expected to mirror the results of Experiment 1. For another group (the “incompatible” group), choosing and depressing the homologous finger resulted in a different action effect compared to the one that would have been triggered by responding with the cued finger (and, instead, responding with the non-homologous finger resulted in a similar action effect as would have been triggered by the prepared response). Three possible outcomes seem possible. First, if action effects do not play any role in determining which alternative is chosen in the free-choice trials, this group should produce the same results as the compatible group. Second, if only action effects count, the results from the compatible group should reverse: Participants should choose the non-homologous finger more often since it will result in a similar visual effect. Third, and perhaps most likely, both action effect similarity and finger homology contribute to response choice. In this case, participants of the incompatible group would choose the homologous finger less frequently than those in the compatible group do. Perhaps, homologous and non-homologous fingers are chosen equally often, which would be predicted if finger homology and visual effect similarity determined response choices to a similar extent.

3.1. Methods

3.1.1. Participants

Twenty undergraduate students participated for course credit (15 females; mean age = 21.9 years) and fulfilled the same criteria as in Experiment 1.

3.1.2. Apparatus, stimuli, and procedure

This experiment was similar to Experiment 1 with few changes. First, only go-to blocks were administered. Second, above the four squares, larger rectangles were drawn. Pressing a response key either made a column grow low or high, the action effect (see Fig. 1, upper panel). Four possible combinations of low/high-growing columns were mapped to the responses; two of them coupling homologous fingers with similar effects, and the other two coupling homologous fingers with different effects (see Fig. 1, lower panel). The response–effect mapping was counterbalanced across participants.

Each participant performed six blocks. Blocks 1 and 2 were familiarization blocks of ten trials each. In Block 1, only a cue occurred and participants were to press the corresponding key and experience the action effects. In Block 2, the (arrow) stimulus was also presented and the trials were as described for go-to blocks in Experiment 1, with the exception of the action effects following a key press. Block 3 consisted of 80 trials similar to Block 1 to learn the response–effect mapping. Block 4 consisted of 80 trials as in Block 2. Block 5 repeated 40 trials as in Block 3, and the final Block 6 consisted of 80 trials as in Block 4.

3.1.3. Data treatment and analyses

Trials with errors were excluded prior to the following analyses. The main analysis focused on the percentages of homologous finger choices in free-choice trials. Participants were split in two groups, those who produced similar action effects with homologous fingers (compatible group) and those who produced different action effects with homologous fingers (incompatible group). The percentages of homologous finger choices for both groups were then compared via a two-sample t-test. Additionally, the percentages were tested against a fixed value of 50% with one-sample t-tests. RTs were analyzed with a mixed ANOVA with trial type (forced-choice vs. free-choice: homologous vs. free-choice: non-homologous) as a repeated measure and group (compatible vs. incompatible) as a between-subjects variable. RTs were deemed outliers if they deviated from the mean by more than 2.5 SDs calculated separately for each participant and design cell (2.7% of the trials). Error percentages were analyzed by means of a mixed ANOVA with trial type (forced-choice vs. free-choice) as a repeated measure and group as a between-subjects variable.

3.2. Results

Participants in the compatible group chose the homologous finger in 61.5% of the trials. This value is significantly different from 50%, $t(9) = 3.06$, $p = .014$. In contrast, for the incompatible group, the corresponding value was 51.2%, which was not significantly different from 50%, $t(9) = 0.46$, $p = .654$. Most importantly, the observed percentages for homologous finger choices differed significantly between groups, $t(18) = 2.25$, $p = .037$.

Mean correct RTs are summarized in Table 2. The main effect of trial type was significant, $F(2,36) = 44.56$, $p < .001$, $\eta_p^2 = .71$, $\varepsilon = .63$, as was the main effect of group, $F(1,18) = 5.51$, $p = .031$, $\eta_p^2 = .23$. RTs were faster in forced-choice trials compared with free-choice trials and overall slower in the incompatible group. The interaction was not significant, $F(2,36) = 2.76$, $p = .077$, $\eta_p^2 = .13$.

Participants in the compatible group made errors on 2.1% of the free-choice trials and 2.3% of the forced-choice trials. The respective values for the incompatible group are 2.3% and 3.3%. No effect reached significance, all $F\text{s} \leq 0.49$, all $p\text{s} \geq .493$.

Table 2
Mean correct RTs [ms] in Experiment 2 as a function of trial type and group.

Trial type	Compatible group	Incompatible group
Forced-choice	413	486
Free-choice: homologous	542	712
Free-choice: non-homologous	566	729

3.3. Discussion

As expected, the compatible group chose the homologous finger more frequently than the non-homologous finger, very similar to the results of go-to blocks in Experiment 1. For the incompatible group, the percentage of homologous finger choices was significantly smaller than for the compatible group and the percentage was not statistically different from 50%. Again, RTs in forced-choice trials were much faster than in free-choice trials. They were also slower for the incompatible group, reassuring that the effects were successfully coupled with the responses: Coupling homologous fingers with different visual effects appears to impair overall performance and both finger homology status and effect identity play a role when selecting a response in the free-choice trials. This is also evident in the fact that the choice bias of the compatible group was not reversed but still absent for the incompatible group. In sum, however, the results from Experiment 2 clearly point to the fact that beyond the mere anatomical finger homology status, the action effects resulting from homologous or non-homologous finger responses do also play a role in determining the actual response (see also Kunde et al., 2002).

4. General discussion

Which action is favored when humans cannot execute an initially planned action but have to switch to one of several alternative options? There is evidence that subtle, even unconsciously processed, information in the environment affects the choice (e.g., Heinemann et al., 2013; Kiesel et al., 2006; Schlaghecken & Eimer, 2004). Khan et al. (2010) demonstrated an influence of the anatomical status of the prepared response. In their Experiment 1, participants prepared a response with the left or right index or middle finger but were then on some trials to carry out a response with the other hand. In this case, they more frequently chose the homologous finger to respond with. Experiment 1 of the present paper was a close replication of this experiment and results were essentially the same. First, we also observed a larger percentage of homologous finger choices when participants prepared one particular response (in go-to blocks). Second, we also observed absence of this advantage when participants were to prevent the cued response in the case of a forced-choice trial (in no-go-to blocks). Khan et al. suggested that inhibiting the cued response "would bias choices away from a homologous finger response in the free-choice situation" (p. 177), but no signs thereof were observed in their and our Experiment 1. Frankly, we can only speculate about the reasons at present. Along the lines suggested by Khan et al., it might be that explicit exclusion of one response led to preparation or sub-grouping of all other three response options. If this were true, the employed instructions were not suited to test how inhibition affects other response choices and future research should develop a paradigm to address this issue with more confidence. Third, responses in the forced-choice trials were much faster compared with free-choice trials, suggesting that participants did not strategically prepare the homologous finger simultaneously and therefore produce the bias.

However, the advantage of homologous finger choices was apparently not solely due to this anatomical characteristic. The fact that homologous fingers also imply perceptual symmetry (e.g., Mechsner & Knoblich, 2004; Mechsner et al., 2001) and comparable body-related action effects (Janczyk et al., 2009) suggests that these factors also do play a role. In fact, in Experiment 2, the advantage of homologous fingers was absent when homologous fingers led to different visual action effects. On the other hand, the advantage was not reversed indicating that both effect identity and homology status are of some importance and exerted opposing influences in the incompatible group of Experiment 2. To be precise here, we manipulated visual environment-related action effects. Thus, we can say with certainty only that this type of action effects modulated the effects of finger homology. As said in the introduction, it is rather difficult to really manipulate body-related action effects, and thus our conclusion that body-related action effect played a role in the results is only indirect. At the same time, however, we see no reason for different functional roles of body- and environment-related action effects (see also Pfister et al., 2014). A final remark concerns the assumption that participants actually prepared the cued response. For one, the empirical results suggest that there was a special role of this particular response to some extent, prompting the formation of subgroups. However, there is in fact no other empirical validation whether or not the cued response was prepared. Because the probability of the other response (in a forced-choice trial) and of the other task was 50%, participants would not necessarily benefit from this preparation. It remains thus interesting to see whether increasing the frequency with which the cued response is actually produced would boost the response frequency effect.

Interpreted in the framework of the Grouping Model (Adam et al., 2003), the present results suggest that the formation of subgroups also happens in relation to the effects resulting from actions. In particular, in our case, the similar visual action effects can be described as, for example, symmetrical, and the subgroups comprised exactly those responses that would give rise to these effects. If re-programming was necessary, the other member of this subgroup was equipped with a head start giving rise to a higher execution frequency (as in the present study) or a faster execution latency if entirely determined by an external stimulus (as in the study by Kunde et al., 2002). From an ecological perspective, such subgrouping of effect-corresponding motor actions makes sense. It might serve as a backup, which provides a functionally equivalent motor substitute, in cases where planned actions for sudden reasons fail.

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