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ORIGINAL ARTICLE

Learning at any rate: action–effect learning for stimulus-based actions

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Abstract Recent studies reported converging evidence for action–effect associations if participants adopted an intention-based action control mode in free choice conditions, whereas no evidence for action–effect associations was found when participants adopted a stimulus-based mode in forced choice conditions. However, it is not yet clear whether action control modes moderate acquisition or usage of action–effect associations. In the present experiment, two groups of participants underwent an acquisition phase consisting of either free or forced choice key presses that produced irrelevant, but contingent effect tones. In a subsequent test phase, participants freely chose the key to press after former effect tones were presented. A reliable consistency effect resulted for both the groups, i.e. participants preferred the key that produced the irrelevant tone in the preceding acquisition phase. In combination with prior findings, this consistency effect suggests that usage, but not acquisition of action–effect associations depends on an intention-based action control mode.

Introduction

Adaptive behaviour relies on the ability to learn relations between own actions and contingently following effects. Only if an organism has acquired different action–effect (A–E) associations, it will be able to select an appropriate action to produce a desired outcome.

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Not surprisingly, a huge body of research explored such A–E associations and a prominent line of studies explicitly targeted their acquisition. Following a suggestion by Greenwald (1970), these studies typically consisted of two distinct experimental phases. In an acquisition phase, participants performed a series of actions that produced distinct sensory effects so that A–E associations could be learned. In a subsequent test phase, the former action effects were presented as imperative stimuli to assess whether A–E learning took place. In line with the ideomotor principle (e.g., Herbart, 1825), it is assumed that presenting a former action effect automatically activates the representation of 'its' action (for recent perspectives, see Kunde, Elsner, & Kiesel, 2007; Hoffmann et al., 2007).

This backward activation was reported for two different test phase designs that were introduced by Elsner and Hommel (2001). In this study, participants first acquired A–E associations between freely chosen left or right key presses and contingently following low or high pitch effect tones. As first test phase design, Elsner and Hommel's Experiment 1 employed a *forced choice test phase* in which participants had to respond to the former effect tones either with constant or reversed tone-key mapping. In this forced choice test phase, participants responded faster with a non-reversed mapping when compared with a reversed mapping (the *non-reversal advantage*). As second test phase design, Experiments 2–5 employed *free choice test phases* in which participants were asked to select one of the two responses at random after a former effect tone was presented together with a go-stimulus. In these free choice test phases, participants chose the key above chance that had produced the respective effect tone in the acquisition phase (even if the acquisition phase consisted just of one single trial; cf. Dutzi & Hommel, 2009). This effect is referred to as *consistency effect* hereafter.

Both test phase designs were used in numerous studies that highlighted different aspects of A–E associations. Independent of their actual focus, these studies reliably yielded a non-reversal effect when a forced choice test phase was employed and a consistency effect when a free choice test phase was employed (see Fig. 1 for several examples).

Although the design of the test phase varied over studies, the acquisition phases usually required free choices between the response alternatives like the original experiments of Elsner and Hommel (2001). Only recently, Herwig, Prinz, and Waszak (2007) and Herwig and Waszak (2009) pointed out that the design of the acquisition phase does affect the results in the test phase. In a series of experiments, they contrasted the typical *free choice acquisition phase* with a *forced choice acquisition phase*. In this forced choice acquisition phase, participants pressed a left or right key in response to an imperative stimulus that determined which key was to be pressed. Each key press again triggered a distinct and contingent effect tone. The impact of these two acquisition phases was assessed in a forced choice test phase that yielded a reliable non-reversal advantage for the free choice acquisition group, but not for the forced choice acquisition group.

To account for this difference, Herwig et al. (2007) postulated two fundamentally different *action control modes*: intention-based and stimulus-based mode (cf. also Wenke, Waszak, & Haggard, 2009; Keller et al., 2006). Participants in the free choice acquisition group are supposed to adopt an intention-based action control mode that relies on the acquisition and usage of A–E relations as assumed by the ideomotor principle. In contrast, participants in the forced choice acquisition group are supposed to adopt a stimulus-based action control mode that relies on the acquisition and usage of stimulus–response (S–R) associations. Consequently, only participants in the free choice acquisition group could use A–E associations in the subsequent test phase, while participants in the forced choice acquisition group are not supposed to acquire any A–E associations.

However, there is an alternative account for the findings of Herwig et al. (2007). Participants in both the groups might have acquired A–E associations, but only participants in the free choice acquisition group actually applied the A–E associations in the test phase. Participants in the forced choice acquisition phase might have switched to S–R-based action control as suggested by Herwig et al. even though they had built up A–E association in the preceding test phase. Evidence in support of this idea is provided by experiments on response–effect compatibility (Kunde, 2001, 2003) and stimulus–effect compatibility (Hommel, 1993, 1996). For instance, participants of Hommel (1996, Exp. 3) performed left and right key presses as forced choice reactions to visual target stimuli. Each key press contingently produced a high or low pitch tone and, crucially, the target stimulus was also accompanied by one of these tones (the inducing stimulus). Responses were faster when the inducing stimulus matched the action effect as opposed to non-matching tones. Thus, there is evidence for A–E associations under forced choice conditions at least when A–E relations are constantly reinforced (cf. also Kunde, 2001, 2003). Please note that this view is in line with the results of Stock and Hoffmann (2002) who reported a general preference for A–E learning when compared with S–R learning even in situations where much simpler S–R relations might allow equally adaptive behaviour.

These findings strongly support our alternative account for the findings of Herwig et al. (2007): A–E relations might be learned irrespective of the applied action control mode. We tested this alternative explanation by applying forced and free choice acquisition phases like Herwig et al. (2007), but

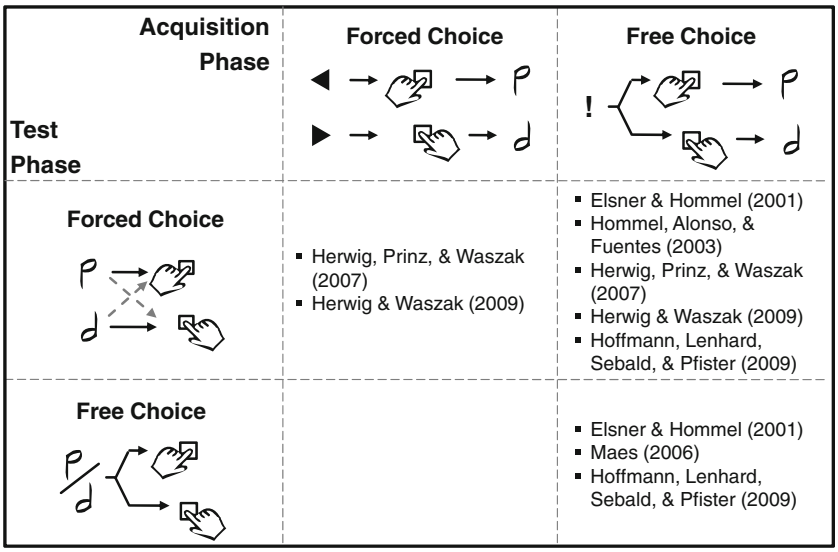

Fig. 1 Acquisition and test phase designs employed in the study of action–effect (A–E) associations. Different hand icons represent different actions and different tone icons represent different effects even though not all studies mentioned here used auditory action effects. Evidence for A–E associations was present when a free choice acquisition phase was used—independent of the test phase design. In contrast, no evidence for A–E associations was found when a forced choice acquisition phase was followed by a forced choice test phase

substituted their forced choice test phase by a free choice test phase. If the action control mode—induced by free or forced choice trials—affects the learning of A–E associations, only the free choice acquisition group is expected to show a consistency effect in the test phase as only this group would have formed the necessary A–E associations. In contrast, if the action control mode affects primarily the usage of A–E associations, a consistency effect is expected also for the forced choice acquisition group.

Method

Participants

Thirty-two participants (10 males, 1 left handed) received either course credit or were paid for participation. The mean age was 25.28 years (SD = 7.01). Participants were naive as to the purpose of the experiment and reported normal or corrected to normal vision and hearing.

Apparatus, stimuli, and procedure

The acquisition phase consisted of one practice block of eight trials and four blocks of 50 trials. Each trial started with an asterisk (0.3° × 0.3°) that was centrally presented on a 17″ monitor. For the free choice acquisition group, the asterisk was always white and participants were instructed to choose one of the keys spontaneously and not to use any strategy. For the forced choice acquisition, the asterisk was either red or green and instructed participants to press a corresponding left or right key. The assignment of asterisk colours to keys was counterbalanced across participants. For both groups, key presses were carried out with the left and the right index finger. Each key press contingently triggered a low or high pitch sinusoidal tone (400 vs. 800 Hz) and the key-tone assignment was counterbalanced across participants. Trials with response anticipations (RT < 100) and response omissions (RT > 1,000 ms) were repeated at a random point during the remainder of the block. After each block, participants in the forced choice acquisition group were informed about their mean reaction time and the number of errors. Participants in the free choice acquisition group were informed about their mean reaction time and the distribution of left and right key presses.

The test phase introduced a go/nogo-task and was identical for both groups of participants; it consisted of one practice block of eight trials and five blocks of 20 valid go-trials. Each trial started with the presentation of a white asterisk (0.3° × 0.3°) that was accompanied by one of three tones—either one of the former effect tones or a new tone (600 Hz and of a different, metallic quality). For the two tones of the acquisition phase, participants were instructed to freely choose one of the keys (go-trials). They were explicitly instructed to decide spontaneously and randomly between both alternatives and not to use any strategy. The new tone served as nogo-signal for the participants (cf. Elsner & Hommel, 2001, Exp. 3B; Hoffmann, Lenhard, Sebald, & Pfister, 2009, Exp. 2) and appeared with a probability of 50%. Go-trials with response anticipations or omissions were repeated as in the training phase. After each block, participants were informed about their mean reaction time, the number of erroneous responses in nogo-trials and the distribution of left and right key presses in go-trials.

Results

Acquisition phase

On an average, participants in the forced choice acquisition group made errors in 5.1% of all trials and error rates were distributed evenly between left and right key presses, $t(15) = 0.78$, $p = 0.441$, $d = 0.27$. For the free choice group, response frequencies for left (51%) and right (49%) key presses did not deviate from chance, $t(15) = 1.26$, $p = 0.218$, $d = 0.44$. Responses were faster in the free choice acquisition group (233 ms) than in the forced choice acquisition group (353 ms), $t(30) = 8.77$, $p < 0.001$, $d = 3.10$ and RTs for left and right responses did not differ for either of the groups (both p's > 0.488).

Test phase

We excluded all test trials with response anticipations (1.3%) or omissions (1.1%) from data analysis and aggregated the remaining trials to individual percentages of consistent and inconsistent response choices for each participant (Fig. 2).[1] To compare the percentage of consistent

[1] Prior implementations of the current experimental design used two independent criteria for participant selection (Elsner & Hommel, 2001, Exp. 3B; Hoffmann et al., 2009, Exp. 2). As first selection criterion, more than 10% erroneous responses in nogo-trials were considered as an indicator of response selection prior to go-signal onset. This behaviour would lead to reduced consistency effects as a prepared response is unlikely to be affected by tones accompanying the go-signal. This tendency was not present in the current data-set ($r = 0.12$ between the percentage of consistent choices and the number of nogo-errors). As second selection criterion, relative percentages of left and right reactions were compared and participants were excluded from data analysis when the distribution was not considered as even. This procedure is statistically warranted as an uneven distribution of response choices inevitably reduces the chance of finding a consistency effect that might be present in the data. This trend was also present in the current data, indicated by a correlation of $r = -0.15$ between the relative percentage of consistent key presses and the percentage of the preferred response. However, to obtain a conservative estimate of the consistency effect, we did not exclude any participant in the present study.

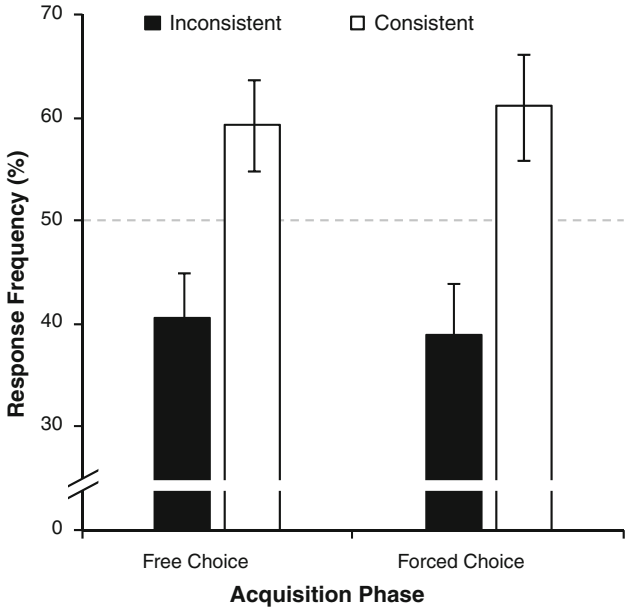

Fig. 2 Relative frequencies and standard errors of acquisition–consistent and acquisition–inconsistent response choices in the free choice test phase for both groups of participants. Prior to the test phase, the groups underwent either a free choice or a forced choice acquisition phase

choices to a baseline of 50%, we used a one-sample t test. This test revealed a significant preference of consistent choices for both, the free choice acquisition group, $m = 61\%$, $t(15) = 2.15$, $p = 0.024$ (one-tailed), $d = 0.76$, and the forced choice acquisition group, $m = 59\%$, $t(15) = 2.15$, $p = 0.024$ (one-tailed), $d = 0.76$. In accordance with the nearly identical results in both the groups, a direct comparison of both consistency effects did not approach significance, $t(30) = 0.26$, $p = 0.798$ (two-tailed), $d = 0.09$.

Furthermore, we compared the percentage of consistent choices to the results of previous studies that used a similar design. Elsner and Hommel (2001, Exp. 3B) and Hoffmann et al. (2009, Exp. 2) obtained 60 and 64% consistent choices, respectively, and neither comparison approached significance (both p's > 0.306). Additionally, and in accordance with the findings of Elsner and Hommel (2001) and Hoffmann et al. (2009), there was no difference between RTs in consistent and inconsistent trials for either group (both p's > 0.788).

Discussion

The present experiment investigated whether the acquisition of action–effect associations depends on the mode of action control (Herwig et al., 2007). According to Herwig et al., only intention-based, i.e. freely chosen, actions enable acquisition of A–E associations. On the contrary, stimulus-based actions are assumed to favour the acquisition of S–R associations.

In the current study, we compared a free and a forced choice acquisition phase (cf. Herwig et al., 2007), but employed a test phase with freely chosen actions instead of forced choice reactions. In this free choice test phase, participants preferred acquisition–consistent responses irrespective of the type of acquisition phase. The resulting consistency effects did not differ between groups and the effects did not differ from the effects reported for previous experiments that used free choice trials in both, acquisition and test phase (Elsner & Hommel, 2001; Hoffmann et al., 2009). These results indicate that the acquisition of A–E associations does not depend on whether participants perform forced choice responses in a stimulus-based action control mode or free choice responses in an intention-based action control mode.

This conclusion is in line with the prior observations of A–E learning in sequential forced choice RT tasks (e.g. Hoffmann, Sebald, & Stöcker, 2001; Ziessler, 1998), task-switching settings (Kiesel & Hoffmann, 2004), stimulus–effect compatibility studies (Hommel, 1993, 1996), and response–effect compatibility studies (e.g., Kunde, 2001, 2003; Kunde, Koch, & Hoffmann, 2004). In these designs, A–E learning was always indicated, despite participants performed forced choice actions only. Furthermore, this conclusion is in line with the reports of A–E learning for forced choice actions comparable to those of Herwig et al. (2007) when one single action was performed in an acquisition phase with intermixed free and forced choice trials (Kühn, Elsner, Prinz, & Brass, 2009, Exp. 3).

In line with these studies, the current results suggest that action control modes do not predominantly determine whether A–E associations are learned, but rather whether existing A–E associations are used for behavioural control. Thus, even though A–E relations seem to be learned independently of the current action control mode, we conjecture that A–E relations are not used if a stimulus-based action control mode is adopted. In this mode, the determination of the action passes from the 'will' to the 'object' at which it is typically performed, as already described by Ach (1935; "voluntionale Objektion"). Accordingly, anticipations of action effects play no role in stimulus-based action control. In contrast, if an intention-based mode is adopted, A–E associations are actively used for the selection, initiation, and execution of an action.

At first glance, this interpretation seems to be at odds with the typical non-reversal advantage reported for experiments with free choice acquisition phases and subsequent forced choice test phases (e.g., Elsner & Hommel, 2001; Hoffmann et al., 2009; Hommel, Alonso, & Fuentes, 2003; see also Fig. 1). In these studies, A–E associations clearly influenced reaction times even though participants

encountered only forced choice trials during the test phase which are supposed to induce a stimulus-based action control mode. To account for this conceptual issue, we argue that actions are intentionally controlled by default switching between both action control modes and does not occur equally fast in both directions. Thus, if an intention-based mode is adopted in a free choice acquisition phase, it will be maintained even under forced choice conditions in the test phase (cf. Prinz, 1998). In contrast, if participants have adopted a stimulus-based mode during the forced choice acquisition phase they will remain in this mode if they continue to perform forced choice actions in the test phase, but they will rapidly switch to the default intention-based mode if free choices are required.

We are aware that this hypothesis is speculative as our data merely suggest that A–E learning is independent of the applied action control mode. Thus, the conditions under which acquired A–E associations are or are not used for the control of current behaviour remain to be further explored.

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