Psychological Research (2015) 79:463–477
DOI 10.1007/s00426-014-0580-6

ORIGINAL ARTICLE

No differences in dual-task costs between forced- and free-choice tasks

Markus Janczyk · Sophie Nolden · Pierre Jolicoeur

Received: 28 November 2013 / Accepted: 2 June 2014 / Published online: 20 June 2014

Abstract Humans appear to act in response to environmental demands or to pursue self-chosen goals. In the laboratory, these situations are often investigated with forced- and free-choice tasks: in forced-choice tasks, a stimulus determines the one correct response, while in free-choice tasks the participants choose between response alternatives. We compared these two tasks regarding their susceptibility to dual-task interference when the concurrent task was always forced-choice. If, as was suggested in the literature, both tasks require different "action control systems," larger dual-task costs for free-choice tasks than for forced-choice tasks should emerge in our experiments, due to a time-costly switch between the systems. In addition, forced-choice tasks have been conceived as "prepared reflexes" for which all intentional processing is said to take place already prior to stimulus onset giving rise to automatic response initiation upon stimulus onset. We report three experiments with different implementations of the forced- vs. free-choice manipulation. In all experiments we replicated slower responses in the free- than in the forced-choice task and the typical dual-task costs. These latter costs, however, were equivalent for forced- and free-choice tasks. These results are easier to reconcile with the assumption of one unitary "action control system."

M. Janczyk (✉)
Department of Psychology III, University of Würzburg, Röntgenring 11, 97070 Würzburg, Germany
e-mail: markus.janczyk@uni-wuerzburg.de

S. Nolden · P. Jolicoeur
Department of Psychology, University of Montreal, Montreal, Canada

Introduction

There is a varied and ever more sophisticated literature in the cognitive psychology of human action control. Recently, there has been a growing interest in a distinction between actions performed in response to environmental demands and actions driven by self-chosen goals. The former have been termed 'stimulus-based', 'externally triggered', or 're-actions', whereas the latter have been termed 'voluntary', 'intention-based', 'self-generated', or 'goal-directed' actions (e.g., Brass & Haggard, 2008; Herwig, Prinz, & Waszak, 2007; Passingham, Bengtsson, & Lau, 2010a; Keller et al., 2006; Waszak et al., 2005).

Two kinds of actions?

This distinction is clearly a convenient simplification: in most, if not all situations (the unconditioned reflex may be an exception), both aspects will come into play, perhaps to varying degrees (see Passingham et al., 2010a; Schüür & Haggard, 2011). For now, however, we will keep this distinction and speak of stimulus- or goal-driven actions. With these terms we point to the particular aspect that predominantly determines the accuracy or appropriateness of an action.

One often-employed way to operationalize both kinds of actions is to use forced-choice and free-choice tasks (Berlyne, 1957a). In forced-choice tasks, each member of a set of possible stimuli is unambiguously mapped to one specific response. In Berlyne's terminology, a polar decision is required and to each stimulus only one response is correct. In free-choice tasks, an arbitrary decision is required and the participant has to choose from a set of responses where "one response is quite as good as another" (Berlyne, 1957a, p. 108; note that a stimulus is presented nonetheless in free-choice tasks and used as the starting point for the response time interval). A stable and robust finding is that responses are typically faster in forced- than in free-choice tasks. Before we consider this effect below in more detail, we briefly review several lines of research that aimed at showing differences between these types of tasks (and thus the corresponding types of actions).

Actions lead to changes in the environment, that is, to action effects. They can range from the proprioceptive feedback from moving an effector to more external or remote consequences, such as concomitant auditory or visual events. The generative role of action effects in action selection has been highlighted by ideomotor theory (Harleß, 1861; Herbart, 1825; James, 1890; Lotze, 1852; for historical comments, see Pfister & Janczyk, 2012; Stock & Stock, 2004) and its modern descendants such as the Theory of Event Coding (Hommel, Müsseler, Aschersleben, & Prinz, 2001): once associations between actions and effects have developed, actions are to be accessed via anticipating their effects. Evidence for this basic claim has been provided by various experimental paradigms (e.g., Elsner & Hommel, 2001; Kunde, 2001; see also Janczyk & Kunde, 2014).

Some authors have suggested that the relation of an action and its immediate sensory consequences (action effects) depends on the type of action (Herwig & Waszak, 2009, 2012; Herwig et al., 2007; see also Gaschler & Nattkemper, 2012, and Pfister, Kiesel, & Melcher, 2010). According to this reasoning, only for goal-driven (free-choice task; in their terminology: intention-based) actions—but not for stimulus-driven (forced-choice task; in their terminology: stimulus-based) actions—long-term associations with the respective effects are learned and could consequently be exploited as a means for action selection. In contrast, other studies have shown that even forced-choice tasks give rise to such associations (Pfister, Kiesel, & Hoffmann, 2011). There are also a number of studies in which the correct response was entirely determined by a stimulus, hence a forced-choice, stimulus-driven task, but action effects nevertheless affected performance (e.g., Janczyk, Pfister, Crognale, & Kunde, 2012; Janczyk, Pfister, Hommel, & Kunde, 2014; Janczyk, Pfister, & Kunde, 2012; Janczyk, Skirde, Weigelt, & Kunde, 2009; Kühn, Elsner, Prinz, & Brass, 2009, Exp. 3; Kunde, 2001; Kunde, Pfister, & Janczyk, 2012; Wolfensteller & Ruge, 2011). These results are clearly not in line with the argument of Herwig and colleagues. Moreover, there appear to be no differences between forced- and free-choice tasks, and thus stimulus- and goal-driven actions, on a shorter time-scale: for both tasks, associations of actions and their effects develop within one trial. Subsequently, these associations bias responses in the next trial to the same degree (Herwig & Waszak, 2012; Janczyk, Heinemann, & Pfister, 2012).

Electrophysiological differences between forced-choice and free-choice tasks were also investigated in several studies. One finding is an enhanced P3 complex in forced-choice compared to free-choice tasks (Fleming, Mars, Gladwin, & Haggard, 2009; Keller et al., 2006; Waszak et al., 2005).[1] This difference has been interpreted as a "clear sign of stimulus-related activity" (Waszak et al., 2005, p. 354; see also Keller et al., 2006) reflecting binding processes of stimuli and responses, whenever the stimuli prescribe the appropriate responses (see also Verleger, Jaskowski, & Wascher, 2005). Thus, such finding suggests a critical role of the stimulus, but does not unambiguously provide evidence that free- and forced-choice tasks are processed in qualitatively different ways. In fact, a recent EEG study provided evidence that both tasks rely on a common central mechanism (Hughes, Schütz-Bosbach, & Waszak, 2011), although preparation of a response in the free-choice task may be more flexible and easily altered in comparison to a forced-choice task (Fleming et al., 2009).

Early imaging studies with non-human primates suggested the implication of lateral areas in stimulus-driven actions and of medial areas in goal-driven actions (Goldberg, 1985). More recent studies, however, suggest only a partial dissociation. While several areas contribute to all actions, goal-driven actions appear to rely more on a network including the rostral cingular zone (RCZ) and the supplementary-motor area (SMA; e.g., Jahanshahi et al., 1995; Rowe, Hughes, & Nimmo-Smith, 2010; Passingham et al., 2010a; Wiese et al., 2004). The RCZ has been ascribed a role in selecting "what" action to do; however, its exact function is debated. Some authors suggest that the RCZ establishes associations of actions and their consequences (e.g., Krieghoff, Brass, Prinz, & Waszak, 2009; Müller, Brass, Waszak, & Prinz, 2007). Others suggest that free-choice tasks (and thus goal-driven actions) imply more conflict and uncertainty (Berlyne 1957a, b; Cunnington, Windischberger, Deecke, & Moser, 2003). Accordingly, the RCZ might be activated more for the required conflict monitoring (Botvinick, Braver, Barch, Carter, & Cohen, 2001). A similarly unclear picture applies to the SMA. Some authors argue for its crucial role in goal-driven actions as investigated with free-choice tasks (e.g., Passingham et al., 2010a). This view, however, is not accepted in general and has led to an animated debate about the exact role of the SMA and methodological issues concerning the nature of the differences in underlying mechanisms mediating free-choice and forced-choice tasks (Nachev & Husain, 2010; Nachev, Kennard, & Husain,

[1] In addition, the stimulus-locked lateralized readiness potential has been shown to be larger in forced-choice compared to free-choice tasks in one study (Waszak et al., 2005), but not in another (Keller et al., 2006).

2008; Passingham et al., 2010a, b; see also Schüür & Haggard, 2011).

The RT difference between forced- and free-choice tasks

Although these lines of research suggest some differences, the conclusions at the same time remain ambiguous. It is thus unclear whether a conceptual distinction of two qualitatively different classes of actions is warranted or not. Before we continue with the aims of the present research, we consider possible reasons for the typically reported RT difference between forced- and free-choice tasks (e.g., Berlyne, 1957a).

Of course, the longer RTs in free-choice than in forced-choice tasks may result from what traditionally seems to be seen as the crucial difference between forced- and free-choice tasks to render them suitable to operationalize stimulus- and goal-driven actions. To illustrate this difference, consider a situation in which participants have two response options, say two response keys, and three different stimuli are employed: two of them are mapped to specific response keys (the forced-choice task), whereas the third stimulus indicates the free-choice task and participants have to choose from the two possible response options. The longer RTs for the free-choice task in the foregoing example can be interpreted based on a model by Brass and Haggard (2008). According to this model, several components of human actions must be distinguished, and for each of these components decisions must be made: one has to decide whether to act at all, when to act, and last but not least, what action to perform (hence called the what-when-whether model). Applied to forced- and free-choice tasks, the whether-decision should be the same for both tasks, as should be the when-decision (given suitable instructions for fast responses). However, the what-decision must still be made in free-choice but not in forced-choice tasks and the associated longer RTs may reflect the additionally required decision making processes. Along these lines, and important for the present purposes, it has even been suggested that two different "action control systems" handle stimulus- and goal-driven actions (e.g., Astor-Jack & Haggard, 2004; Obhi & Haggard, 2004).[2] These two systems were described as acting "exclusive, in that they cannot be simultaneously active" (Astor-Jack & Haggard, 2004, p. 127). Thus, (at least) some processes of both systems cannot run at the same time, but must run serially and a time-costly switch from one system to the other becomes necessary. In a sense then, there exists a bottleneck at one point of processing.

Yet, when thinking in stage logic, the RT difference between free-choice and forced-choice tasks can also have other sources. For example, it is possible that both tasks do not differ with regard to the central (capacity-limited) stages, but rather the perceptual stage of forced-choice tasks may be shorter compared with that of free-choice tasks. Arguments for such reasoning can (1) be based on the implementation intention account introduced by Gollwitzer (1999) because the typical instructions in forced-choice tasks have the "if–then" structure of implementation intentions which are thought to facilitate perception of suitable environmental demands (i.e., the stimuli in our case) and (2) on the assumption of bidirectional links between stimuli and responses (Elsner & Hommel, 2001; Metzker & Dreisbach, 2009). In fact, a recent study used the Psychological Refractory Period (PRP) paradigm (Pashler, 1994) and the locus of slack logic (Schweickert, 1978; see also Janczyk, 2013, or Miller & Reynolds, 2003, for detailed descriptions) to test this possibility (Janczyk, Dambacher, Bieleke, & Gollwitzer, 2014). In Experiments 1 and 2 of this study, the task manipulation (forced- vs. free-choice) interacted underadditively with the stimulus onset asynchrony (SOA), a pattern pointing to the pre-central, perceptual stage as the source for the RT difference. This interpretation was further corroborated with the additive-factors logic (Sternberg, 1969) in Experiment 3. If the RT difference can indeed be attributed to differences in perceptual processing, there would be no reason to assume further qualitatively different and/or additional decisions carried out in the central stage of free-choice tasks.

Not alluding to stage logic, Berlyne (1957a) has described response selection in a more dynamic way and suggested that a response will be emitted eventually if its activation exceeds the activation of the other responses to a certain minimum degree. At the outset of a trial, all action representations are active, but on forced-choice trials the stimuli bias evidence accumulation such that the required difference in activation is achieved earlier than in free-choice trials (see also Berlyne, 1957b). This accounts for the longer RTs in free-choice tasks, while the selection-criterion in both tasks is qualitatively the same (for a similar conclusion, see also Janczyk, Dambacher et al., 2014; Mattler & Palmer, 2012).

The present experiments

We have seen above that various criteria have yielded ambiguous results as to whether two different types of actions should be distinguished or not. To investigate differences and similarities, the study of interference phenomena has proven fruitful in other areas of human

[2] The term "action control systems" is still a bit vague. In our understanding, it refers to two largely different neural networks responsible for carrying out one action type or the other. When referring to this literature, we will, however, continue to use the term "system" although our data does not speak to the neural substrates.

cognition (e.g., memory: Baddeley, 2007; Oberauer & Kliegl, 2006).

In the present study, we applied this approach to the case of forced- and free-choice tasks. In particular, we focused on dual-task interference when one task is always forced-choice and the other could either be free- or forced-choice. A classic approach is to measure performance when two tasks are performed alone (single-task) and when they are performed simultaneously (dual-task) and to compare performances. Hundreds of studies have since shown worse dual-task than single-task performance (i.e., dual-task costs). Given the importance of these performance decrements for time-critical and accuracy-critical activities outside the lab (e.g., driving a car on a highway), this approach seems clearly warranted and important.

The first goal of the present study was thus to provide empirical data of a systematic comparison of the susceptibility of forced- and free-choice tasks to dual-task interference. Note that the question of interest here is not whether forced- and free-choice tasks are susceptible to dual-task interference at all; the question is whether the degree of susceptibility is the same or different for both tasks. The PRP effects observed by Janczyk, Dambacher et al. (2014) for forced- and free-choice tasks confirm that both tasks suffer from dual-task interference. Yet, the size of the PRP effect (sometimes quantified as the RT difference between the shortest and the longest SOA) is a function of the duration of the pre-central and central stages of Task 1, rather than of the central stage of Task 2 (where free- and forced-choice tasks were varied). Thus, we opted here for the classical comparison between single- and dual-task conditions with simultaneous stimulus presentation to assess the amount of dual-task interference. Further, the results of the Janczyk, Dambacher et al. study gave us some empirical backing for the predictions formulated below.

Second, and beyond merely assessing whether dual-task costs are the same or not for both task types, the experiments allow exploring various ideas of the underlying mechanisms mediating performance in forced-choice and free-choice tasks. What can we predict for the patterns of dual-task costs based on the literature?

Forced-choice tasks have sometimes been described with the prepared-reflex metaphor (Hommel, 2000; Woodworth, 1938; see also Janczyk, Pfister, Wallmeier, & Kunde, 2014). According to this metaphor, all intentional, resource-consuming processes take place due to the instructions already before stimuli arrive. Upon arrival of a particular stimulus, response initiation would occur automatically. Such framing suggests less susceptibility to dual-task interference for forced- compared with free-choice tasks. On the other hand, the account suggested by Berlyne (1957a, b)—while explaining the RT difference—does not predict differences in dual-task costs.

According to stage logic, the two interpretations of the RT difference given in the preceding section also make diverging predictions. Here, we assume that in a dual-task situation both tasks are performed in a serial manner with responses given more or less at the same time when no task is prioritized in the instruction. There are two reasons for this: first, serial processing has been argued to be more efficient than parallel processing in many situations (e.g., Logan & Gordon, 2001; Miller, Rolke, & Ulrich, 2009; see also Obhi & Haggard, 2004, who "note that intentional actions are generally performed serially, rather than in parallel", p. 523). Second, and more important, if two different action control systems that cannot be activated at the same time are assumed, they must proceed serially. This excludes parallel processing in general and any predictions based on parallel processing models would not be compatible with this view from the very beginning.[3]

1. Figure 1a illustrates the situation when forced- and free-choice tasks differ in their response selection stages that are handled by different "action control systems" (Astor-Jack & Haggard, 2004; Obhi & Haggard, 2004). If both tasks in a dual-task setting are forced-choice, then the same action control system can handle both tasks. In contrast, if one task is forced-choice and the other free-choice, a switch from one to the other "action control system" is required (the red box in Fig. 1a). In this situation, the RT difference between forced- and free-choice tasks should become larger in dual-task compared to single-task conditions, thus yielding more dual-task costs for free- than for forced-choice tasks. Note that for this situation the order in which the central stages are actually carried out does not matter.
2. The opposing possibility assumes that forced- and free-choice tasks (a) differ in the duration of their perceptual stages but (b) do not entail qualitatively different central stages and thus there is no need to switch between different "action control systems" (see Fig. 1b). In this situation, different predictions can be made depending on which task's central stage is processed first. If always the free-choice task is processed first, we still expect longer RTs for the free-choice task, but the same dual-task costs for both the free- and the forced-choice task (see Fig. 1b_1). In contrast, if the forced-choice task is always carried out first, the RT difference between free-choice and forced-choice tasks should be eliminated in the dual-task situation because the perceptual stage of the free-choice tasks is processed while the central stage of the

[3] We will discuss one special case of parallel processing in the "General Discussion".

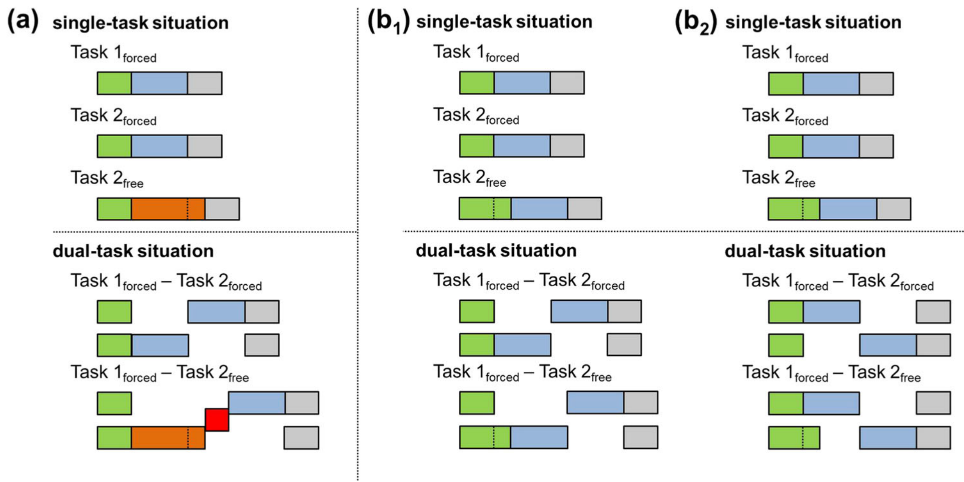

Fig. 1 Illustration of the three scenarios for forced- and free-choice tasks as explained with stage-logic (*green and gray boxes* indicate perceptual and motor stages that run in parallel with other stages). **a** The RT difference arises from qualitatively different central stages in forced- (*blue box*) and free-choice tasks (*orange box*) implying a time-costly switch between different action systems (indicated by the *red box*). $\mathbf{b_1}$, $\mathbf{b_2}$ The RT difference is due to a shorter pre-central perceptual stage in the forced-choice tasks and both forced- and free-choice task rely on the same action system (*blue box*), thus not requiring a switch. Both panels ($\mathbf{b_1}$) and ($\mathbf{b_2}$) differ, however, with regard to which task's central stage is processed first (see text for more explanations)

other task is already ongoing. Accordingly, dual-task costs should be smaller for free- than for forced-choice tasks (see Fig. 1b_2). A priori, it is difficult to tell one of these two possibilities more likely. On the one hand, a first-come, first-serve strategy seems viable (Fig. 1b_2). On the other hand, in our experiments the task with the forced- vs. free-choice manipulation employed always visual stimuli and manual responses. In the dual-task literature, this pairing has been described as a favorable one (e.g., Hazeltine, Ruthruff, & Remington, 2006). Thus it might always be this task that is handled first (as in Fig. 1b_1). Importantly, neither situation predicts larger dual-task costs for the free-choice situation. Note also that, of course, one might argue that a "traditional" task-switch (see Kiesel et al., 2010, for a review) is required here as well as in the previous scenario. However, if, as assumed in the previous scenario, both tasks are indeed carried out by different "action control systems", then switching between these different systems still incurs an extra cost.

There is in fact some ambiguity in the literature. Several authors base their claim of two "action control systems" on the finding of additional costs when switching from one system to the other is necessary (Astor-Jack & Haggard, 2004; Obhi & Haggard, 2004). Such switch costs have, however, been observed in these studies for simple responses. On the other hand, in the majority of the literature, free- and forced-choice tasks as we use here are employed to operationalize the assumed two kinds of actions (and thus to address the two different "action control systems"). Notably, in one experiment a two-alternative forced-choice task was used instead of a simple response (Astor-Jack & Haggard, 2004, Exp. 3) and in this case no switch costs were observed.

In three experiments we combined a forced-choice task (binary tone discrimination) with another (visual) task that could either be forced- or free-choice. In Experiments 1 and 2, these two variants were randomly intermingled within blocks; in Experiment 3 they were varied blockwise. Performance was measured in single-task conditions as well as in dual-task conditions, where both stimuli appeared simultaneously. There is a debate whether single-task performance provides the appropriate baseline or not (see, e.g., Halvorson, Ebner, & Hazeltine, 2013). As an alternative, some authors use mixed conditions, where on each trial only one stimulus from one task occurs, but both tasks are randomly intermixed. This condition requires participants to be ready to perform each of the two tasks, but given that only one stimulus is presented on each trial, the task is executed without concurrent processing of another stimulus and task. A disadvantage is, however, that in this case a mixture of task switches and repetitions occurs within these blocks. We employed this condition in the experiments; yet, the most important comparison will be that of single- and dual-task conditions.

Experiment 1

Participants performed in two tasks in a classical dual-task paradigm with four different block types: two homogeneous single-task blocks for a visual and an auditory task; a heterogeneous (mixed) single-task block with each task appearing from trial-to-trial in a random order; and a dual-task block with both tasks to be performed simultaneously. An increase of mean response times (RTs) from single-task, to mixed, to dual-task blocks was expected. In the visual task, a forced- vs. free-choice manipulation was implemented and longer RTs were expected in the free-choice variant. The main question was whether dual-task costs would be larger for the free- than for the forced-choice task (Fig. 1a) or not (Fig. 1b).

Method

Participants

Forty-eight naïve people from the Würzburg area participated (mean age: 27.4, 33 female) for monetary compensation or course credit. Written informed consent was obtained prior to the experiment.

Apparatus and stimuli

Experimental procedures were controlled by a standard PC connected to a 17″ CRT monitor. Visual stimuli were the letters H, S, and X, presented in white against a black background until response. Auditory stimuli were two sinusoidal tones (300 and 900 Hz, 50 ms) presented via headphones. Responses were collected via external custom-built keys. Two keys were located to the left of the participants for responses to the visual stimulus with the left index- and middle-finger. Two other keys were located to their right for responses in the auditory task given with the right index- and middle-finger.

Tasks and procedure

In the visual task, participants were to respond to two of the possible letters with a specific response (forced-choice task); when the third letter was presented they were to freely choose between the two possible responses (free-choice task). In the auditory task, they were to respond to the pitch of the tone stimulus.

The experiment consisted of four different block types. In the two types of single-task blocks, only the visual or the auditory task was relevant and accordingly only letters or tones were presented in these blocks. In the mixed blocks, both tasks were relevant and letters and tones were presented randomly intermingled but never on the same trial. In the dual-task blocks, on each trial both a letter and a tone were presented simultaneously. No task was prioritized over the other. Each trial started with a fixation cross (500 ms) and following a blank screen (250 ms) the stimulus was (single-task and mixed blocks) or the stimuli (dual-task blocks) were presented. In case of erroneous responses, no responses within 4,000 ms after stimulus onset, or responses with the wrong hand, error feedback was presented for 500 ms. The next trial started after 1,000 ms.

Single-task blocks comprised 18 trials with the respective stimuli appearing equally often. Mixed blocks comprised 24 trials with the three letters appearing four times each and the two tones appearing six times. Dual-task blocks also comprised 24 trials with the six possible combinations of letters and tones appearing four times. In all block types, stimuli were randomly intermingled. The four different block types (single-task blocks for the visual and the auditory task, mixed block, dual-task block) were repeated six times. The first four blocks (one block of each type) were considered practice and the experimenter stayed in the room to answer questions. Data from these blocks were not analyzed.

Written instructions were given prior to the experiment highlighting the importance of responding quickly while keeping errors to a minimum. For the free-choice task, they further encouraged to avoid any strategies and to choose both options about equally often. Prior to each block, participants were briefly reminded about the now relevant task(s). Stimulus–response mappings of the visual and the auditory task were counterbalanced across participants.

Data treatment and analyses

Trials with general errors (response too late, response prior to stimulus onset) were excluded. Further, for RT analyses, only entirely correct trials were considered and RTs deviating more than 3 SDs from the mean (calculated separately for each participant and analyzed condition) were excluded as outliers (visual task: 1.3 %, auditory task: 1.6 %). Mean RTs of the visual task were submitted to an analysis of variance (ANOVA) with task type (forced-choice vs. free-choice) and block type (single-task vs. mixed vs. dual-task) as repeated measures. We followed up these analyses by comparing single-task with mixed blocks (=mixing costs) and single-task with dual-task blocks (=dual-task costs) Percentages error (PE) from the visual (only forced-choice trials; it was not possible to commit errors in the free-choice task) and the auditory task and mean RTs in the auditory task were evaluated by means of an ANOVA with block type as a repeated measure. A significance level of $\alpha = .05$ was adopted and when the sphericity assumption was violated, Greenhouse-Geisser corrections were applied. In these cases, uncorrected degrees of freedom are reported supplemented by the ε estimate.

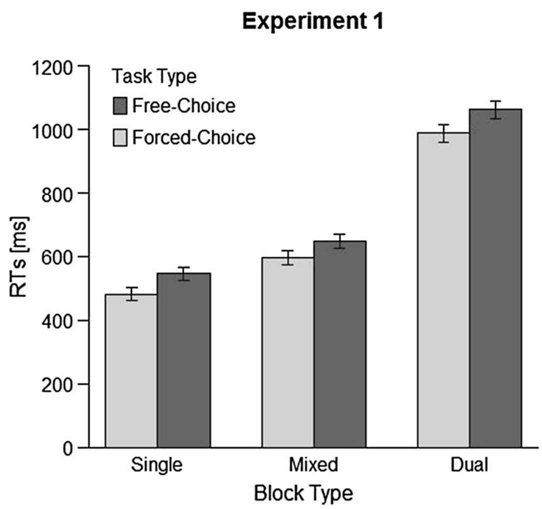

Fig. 2 Mean RTs in the visual task of Experiment 1 as a function of block type and task type. *Error bars* are 95 % within-subject confidence intervals calculated separately for each block type (Pfister & Janczyk, 2013)

Results

Results for the visual task are reported first, as they are theoretically the most interesting ones. Results for the auditory task are reported afterwards.

Visual task (forced- vs. free-choice)

Mean RTs in the visual task are illustrated in Fig. 2. As expected, responses were fastest in the single-task blocks, intermediate in the mixed blocks, and slowest in the dual-task blocks, thus replicating typical dual-task costs. Further, responses were slower in the free-choice than in the forced-choice task, and the dual-tasks costs were about the same size for both the forced- and the free-choice task. Accordingly, the main effect of block type was significant, $F(2,94) = 395.35$, $p < .001$, $\eta_p^2 = .89$, $\varepsilon = .57$, as was the main effect of task type, $F(1,47) = 66.03$, $p < .001$, $\eta_p^2 = .58$. Importantly, the interaction was not significant, $F(2,94) = 1.09$, $p = .341$, $\eta_p^2 = .02$.

The assessment of mixing costs yielded a significant effect of block type, $F(1,47) = 194.54$, $p < .001$, $\eta_p^2 = .81$, and of task-type with lower RTs for the forced- compared with the free-choice task, $F(1,47) = 69.86$, $p < .001$, $\eta_p^2 = .60$. The interaction was not significant, $F(1,47) = 0.64$, $p = .427$, $\eta_p^2 = .01$. The same pattern arose for the assessment of dual-task costs, block type: $F(1,47) = 442.09$, $p < .001$, $\eta_p^2 = .90$; task type: $F(1,47) = 55.25$, $p < .001$, $\eta_p^2 = .54$; interaction: $F(1,47) = 0.38$, $p = .540$, $\eta_p^2 = .01$.

PEs were only analyzed for the forced-choice task as it was not possible to commit errors in the present free-choice task. Participants committed 3.61, 4.20, and 3.55 % errors in the single-task, mixed, and dual-task blocks, respectively. The corresponding ANOVA revealed no significant differences between block types, $F(2,94) = 0.52$, $p = .595$, $\eta_p^2 = .01$.

Auditory task

RTs in this task followed the expected pattern and were fastest in single-task blocks (577 ms), intermediate in mixed block (730 ms), and slowest in dual-task blocks (1,017 ms). The respective ANOVA yielded a significant effect of block type, $F(2,94) = 218.50$, $p < .001$, $\eta_p^2 = .82$, $\varepsilon = .59$. A similar increase was observed for PEs (single-task: 1.94 %, mixed: 3.82 %, dual-task: 5.22 %) and the effect of block type was significant, $F(2,94) = 9.47$, $p = .001$, $\eta_p^2 = .17$, $\varepsilon = .73$.

Discussion

The results of Experiment 1 replicated two typical findings. First, responses in forced-choice tasks were about 66 ms faster than responses in free-choice tasks (Berlyne, 1957a). Second, the comparison of block types revealed the expected pattern with response slowing in mixed and dual-task blocks compared to the single-task blocks, thus mixing and dual-task costs. Of particular importance for the present purpose, these costs were not significantly different between forced- and free-choice tasks—a result not in line with the situation depicted in Fig. 1a.

Experiment 2

In Experiment 1, the three possible stimuli in the forced/free choice task occurred equally often. This, however, comes to the expense that only one-third of the trials were free-choice, while two-thirds of the trials were forced-choice (see also the experiments of Berlyne, 1957a). The difference in RTs between both task types might thus result from different amounts of practice with both task types in the course of the experiment or from expectancies about the next upcoming task. To overcome this potential problem, a different approach to operationalize task types was used in Experiment 2 to determine whether the findings of Experiment 1 were compromised by the difference in the number of trials across task types.

Thus, to replicate and generalize the results from Experiment 1, the forced- vs. free-choice manipulation was realized in a different manner. Participants now had three response options. In forced-choice trials, one specific response was demanded by one stimulus; in free-choice trials, participants were presented with two stimuli and were to choose one of the two corresponding responses. This method circumvents the confound of task type and frequency that occurred in Experiment 1 while avoiding different stimulus frequencies that would result from merely changing the number of trials per task type in a design similar to Experiment 1.[4] As a result, forced- and free-choice trials occur equally often as do all stimuli as well. Further, in Experiment 1 it was unclear whether participants really processed the free-choice stimulus or simply excluded the occurrence of forced-choice stimuli on each trial. This would introduce another difference between both task types. With the present design the exact set of allowed responses in free-choice trials is unclear until stimulus onset and participants are thus required to attend the stimuli in all trials. This approach also conveniently allows us to present forced- and free-choice trials in separate blocks, what we did in Experiment 3.

Method

Participants

Forty-eight new and naïve people from the Würzburg area participated (mean age: 24.8, 39 female) for monetary compensation or course credit. Written informed consent was obtained prior to the experiment.

Apparatus and stimuli

Experimental procedures were controlled by a standard PC connected to a 17″ CRT monitor. Auditory stimuli, responses, and response keys were the same as in Experiment 1 (but with the left hand now). Visual stimuli were three horizontally arranged squares (1.5 cm × 1.5 cm; 1.5 cm between squares). At the onset of a trial, only their white outlines were visible. During trials, one or two of the squares were filled white. Responses in the visual task were collected via three external custom-built keys located to the right of the participants for responses with the right index-, middle-, and ring-finger.

Tasks and procedure

In the auditory task, participants were to respond to the pitch of the tone. In the visual task, in forced-choice trials only one square was filled white and the participants were to press the corresponding key in a spatially compatible mapping (i.e., left square → index-finger, middle square → middle-finger, right square → ring-finger). In free-choice trials, two of the squares were filled white and the participants were to freely choose between the corresponding keys.[5]

The four different block types were single-task blocks (for both the auditory and the visual task), mixed blocks, and dual-task blocks. Each trial started with the onset of the three squares (500 ms). Depending on block type, either a tone was played, the visual stimulus changed (one or two squares turned white), or both. Error feedback was presented for 1,000 ms, and the next trial started after 1,000 ms.

Single-task blocks comprised 18 trials with the respective stimuli appearing equally often. Mixed blocks comprised 24 trials with the two tones appearing six times each and the six different visual stimuli (3 forced-choice, 3 free-choice combinations) appearing twice. Dual-task blocks also comprised 24 trials with the 12 possible combinations of tones and visual stimuli repeated twice. In all blocks, stimuli appeared randomly intermingled. The blocks were presented in the same order (single-task blocks for the auditory and the visual task, mixed block, dual-task block) and were repeated seven times. The first presentation of each block was considered practice and the experimenter stayed in the room to answer questions. Data from these blocks were not analyzed.

Written instructions stressed speed and accuracy, as in Experiment 1. Prior to each block, participants were briefly reminded about the now relevant task(s). The stimulus–response mapping of the auditory task was counterbalanced across participants.

Data treatment and analyses

Analyses were done similar to Experiment 1. The only difference was that it was now possible to commit errors in the free-choice task when participants pressed the one key that was not signaled by the white stimulus squares. Thus, both RTs and PEs from the visual task were submitted to an ANOVA with task type (forced-choice vs. free-choice) and block type (single-task vs. mixed vs. dual-task) as repeated measures. As for Experiment 1, we followed-up the RT analyses by assessing mixing costs and dual-task costs

[4] Another difference between the forced- and free-choice tasks used in Experiment 1 relates to the fact that the forced-choice task entailed a “consistent mapping” of stimuli and responses, while the free-choice task can be construed as entailing a “varied mapping”: to the same stimulus different responses are required. There is evidence for automatic retrieval of responses and/or tasks upon stimulus perception from the task-switching literature (e.g., Koch, Prinz, & Allport, 2005; Waszak, Hommel, & Allport, 2003), and thus the free-choice stimulus might re-activate the last response associatively and lead to increased response conflict. With the design we used in Experiment 2 and 3, this additional difference should be less pronounced.

[5] If one views forced- vs. free-choice tasks as a continuum, this particular task might be a shift toward the forced-choice pole because it requires extracting the two possible stimuli and the respective responses. Still, however, it requires a “free-choice” between the two possible responses.

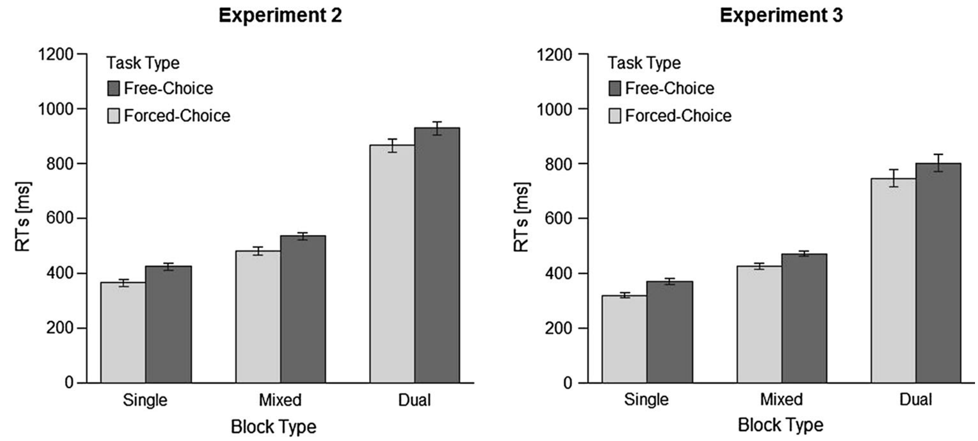

Fig. 3 Mean RTs in the visual task of Experiments 2 and 3 as a function of block type and task type. *Error bars* are 95 % within-subject confidence intervals calculated separately for each block type (Pfister & Janczyk, 2013)

separately. RTs and PEs of the auditory task were submitted to an ANOVA with block type as a repeated measure. As outliers 1.7 and 1.6 % of the trials in the visual and the auditory task, respectively, were eliminated for RT analyses.

Results

Visual task (forced- vs. free-choice)

Mean RTs are shown in Fig. 3 (left panel). As in Experiment 1, responses were fastest in single-task blocks, intermediate in mixed blocks, and slowest in dual-task blocks. In other words, the typical pattern of dual-task costs emerged. Also, responses were faster for forced-choice than for free-choice trials and the dual-task costs were similar in size for both task types. The ANOVA confirmed these patterns. The main effect of block type was significant, $F(2,94) = 314.11$, $p < .001$, $\eta_p^2 = .87$, $\varepsilon = .53$, as was the main effect of task type, $F(1,47) = 81.28$, $p < .001$, $\eta_p^2 = .63$. The interaction was not significant, however, $F(2,94) = 0.35$, $p = .663$, $\eta_p^2 = .01$, $\varepsilon = .81$.

Also as in Experiment 1, mixing costs were significant, $F(1,47) = 416.73$, $p < .001$, $\eta_p^2 = .90$, as was the advantage for forced- over free-choice tasks in this comparison, $F(1,47) = 104.66$, $p < .001$, $\eta_p^2 = .69$. The interaction was not significant, $F(1,47) = 0.50$, $p = .483$, $\eta_p^2 = .01$. The same pattern was observed for the assessment of dual-task costs, block type: $F(1,47) = 364.58$, $p < .001$, $\eta_p^2 = .89$; task type: $F(1,47) = 59.27$, $p < .001$, $\eta_p^2 = .56$; interaction: $F(1,47) = 0.08$, $p = .777$, $\eta_p^2 < .01$.

PEs are summarized in Table 1. Overall, more errors were committed in the forced-choice than in the free-choice task, $F(1,47) = 9.06$, $p = .004$, $\eta_p^2 = .16$, and most errors were made in the dual-task blocks, $F(2,94) = 22.88$, $p < .001$, $\eta_p^2 = .33$, $\varepsilon = .68$. In the mixed blocks, however, a comparable amount of errors was made for both task types, giving rise to a significant interaction, $F(2,94) = 5.25$, $p = .010$, $\eta_p^2 = .10$, $\varepsilon = .88$. As noted in the introduction, the most important comparison is that between single- and dual-task blocks, that is, the assessment of dual-task costs. Thus, an additional 2 × 2 ANOVA was run on PEs for only these two block types, excluding mixed blocks. As expected, both main effects were significant, block type: $F(1,47) = 31.78$, $p < .001$, $\eta_p^2 = .40$, task type: $F(1,47) = 18.96$, $p < .001$, $\eta_p^2 = .29$. Importantly, however, the interaction was no longer significant, $F(1,47) = 1.69$, $p = .200$, $\eta_p^2 = .03$.

Table 1 Percentages error in the visual task of Experiments 2 and 3 as a function of block type and task type

Block type	Experiment 2		Experiment 3	
	Task type		Task type	
	Forced-choice	Free-choice	Forced-choice	Free-choice
Single-task	1.12	0.42	1.00	0.93
Mixed	0.80	0.93	0.97	2.34
Dual-task	3.13	1.91	3.04	3.21

Auditory task

Responses were fastest in single-task blocks (606 ms), intermediate in mixed blocks (745 ms), and slowest in dual-task blocks (936 ms), and the corresponding ANOVA was significant, $F(2,94) = 179.98$, $p < .001$, $\eta_p^2 = .79$. A similar increase in PEs was also observed (single-task: 3.04 %, mixed: 3.91 %, dual-task: 5.18 %), $F(2,94) = 9.20$, $p < .001$, $\eta_p^2 = .16$.

Discussion

The results from Experiment 2 replicated the most important results of Experiment 1. First, responses in the forced-choice task were about 59 ms faster than in the free-choice task, even with the different paradigm used here and when expectancies and different amounts of practice can be excluded. Second, typical dual-task costs were observed and again they were of the same size for the forced- and the free-choice task. These results again suggest that both task types are equally susceptible to interference at the central stage from a secondary task.

Two further aspects of the data deserve attention. First, more errors were committed in forced-choice than in free-choice trials. Together with the longer response times in free-choice trials than in forced-choice trials, this pattern appears to reflect a speed–accuracy tradeoff. In the present context, however, there were three response alternatives in the forced-choice task, with one correct response and two incorrect responses. In the free-choice situation, there were two correct responses and only one incorrect response. Thus, it was more likely to press a wrong key in the forced-choice trials than in the free-choice trials and this might account for the observed difference. Second, in mixed blocks, error rates behaved differently and were not different between forced- and free-choice tasks. Both aspects will again be considered in the discussion of Experiment 3.

Experiment 3

In both Experiment 1 and 2, forced- and free-choice trials were randomly intermingled. A blocked implementation appears difficult with the paradigm used in Experiment 1, because with just one stimulus indicating a free-choice trial, participants could choose a response prior to stimulus onset. In the paradigm used in Experiment 2, however, the exact response could not be chosen with certainty prior to stimulus onset, because the particular pair of locations selected on each trial could vary from trial to trial. This paradigm makes it possible for free- and forced-choice trials to be presented in a blocked way what allows us to generalize the results of Experiment 2 to a broader set of conditions. There is a recent debate as to whether participants, once adopting a “free-choice/intention-based mode,” apply this mode even in a forced-choice situation (Gaschler & Nattkemper, 2012; Pfister et al., 2011). Thus, the blocked presentation of free-choice and forced-choice trials promotes the use of different “action control systems” or modes. In addition, this approach also eliminates possible sequential effects that may underlie the results pattern.

Method

Forty-eight new and naïve people from the Würzburg area participated (mean age: 26.6, 37 female) for monetary compensation or course credit. Written informed consent was obtained prior to the experiment.

In most aspects, this experiment was identical to Experiment 2 with one exception. In all experimental blocks employing the visual task (i.e., the forced- vs. free-choice task) only forced-choice or only free-choice stimuli appeared. For one half of the participants block repetitions 1, 3, and 5 consisted of only forced-choice trials and block repetitions 2, 4, and 6 consisted of only free-choice trials. For the other half of the participants, this order of blocks was reversed. Prior to a block repetition, participants were informed that always only one or always two squares are filled white. An exception was the first presentation of blocks (the practice blocks) where forced- and free-choice trials appeared randomly to familiarize participants with both tasks.

For RT analyses, 1.7 % of the trials were excluded as outliers in both the visual and the auditory task for the same criterion as in Experiment 1.

Results

Visual task (forced- vs. free-choice)

Mean RTs are illustrated in Fig. 3 (right panel) and the obtained pattern was very similar to the previous experiments. Responses were fastest in single-task blocks, intermediate in mixed blocks, and slowest in dual-task blocks, thus the typical pattern of dual-task costs. Responses were also faster in forced-choice than in free-choice blocks and the dual-task costs were of similar size for both task types. Accordingly, the main effects of block type, $F(2,94) = 250.11$, $p < .001$, $\eta_p^2 = .84$, and of task type, $F(1,47) = 68.82$, $p < .001$, $\eta_p^2 = .59$, were significant; the interaction was clearly not significant though, $F(2,94) = 0.32$, $p = .624$, $\eta_p^2 = .01$.

As in the previous two experiments, we observed significant mixing costs, $F(1,47) = 537.13$, $p < .001$, $\eta_p^2 = .92$, as well as the advantage of forced- over free-choice tasks for this comparison, $F(1,47) = 130.05$, $p < .001$, $\eta_p^2 = .73$. The interaction was not significant, $F(1,47) = 0.75$, $p = .390$, $\eta_p^2 = .02$. The same picture emerged for the separate assessment of dual-task costs, block type: $F(1,47) = 295.25$, $p < .001$, $\eta_p^2 = .86$; task type: $F(1,47) = 45.13$, $p < .001$, $\eta_p^2 = .49$; interaction: $F(1,47) = 0.10$, $p = .759$, $\eta_p^2 < .01$.

PEs are summarized in Table 1. Collapsed across both task types, PEs increased from single-task to mixed to dual-task blocks and the corresponding main effect of block type was significant, $F(2,94) = 17.39$, $p < .001$, $\eta_p^2 = .27$. Also, the main effect of task type was significant, $F(1,47) = 4.72$, $p = .035$, $\eta_p^2 = .09$. However, a notable difference was only visible in mixed blocks with more errors in the free- compared with the forced-choice task, giving rise to a significant interaction, $F(2,94) = 3.79$, $p = .037$, $\eta_p^2 = .07$, $\varepsilon = .78$. Therefore, as in Experiment 2, we assessed only the more relevant dual-task costs by comparing single- with dual-task blocks. This analysis confirmed the higher error rate in dual-task blocks, $F(1,47) = 31.83$, $p < .0001$, $\eta_p^2 = .40$, but there was no main effect of task type, $F(1,47) = 0.02$, $p = .878$, $\eta_p^2 < .01$. Importantly, the interaction was not significant any longer, $F(1,47) = 0.32$, $p = .573$, $\eta_p^2 = .01$.

Auditory task

Mean RTs showed the same pattern as in the previous experiments and were fastest in single-task blocks (561 ms), intermediate in mixed blocks (684 ms), and slowest in dual-task blocks (796 ms). The corresponding ANOVA was significant, $F(2,94) = 132.64$, $p < .001$, $\eta_p^2 = .74$, $\varepsilon = .59$. A similar increase in PEs was observed (single-task: 2.01 %, mixed: 4.60 %, dual-task: 6.61 %), $F(2,94) = 39.75$, $p < .001$, $\eta_p^2 = .46$.

Comparison with Experiment 2

Finally, mean RTs in the visual task were analyzed with experiment [2 (random) vs. 3 (blocked presentation)] as an additional between-subjects factor. RTs were faster in Experiment 3 than in Experiment 2, $F(1,94) = 12.34$, $p = .001$, $\eta_p^2 = .12$, and the free-choice task gave longer RTs than did the forced-choice task, $F(1,94) = 150.10$, $p < .001$, $\eta_p^2 = .61$. This difference was the same for both experiments, $F(1,94) = 0.94$, $p = .335$, $\eta_p^2 = .01$. Dual-task costs were observed in both experiments, $F(2,188) = 563.58$, $p < .001$, $\eta_p^2 = .86$, $\varepsilon = .53$ (for the factor block type), but the marginally significant interaction of block type and experiment suggests they were slightly smaller in Experiment 3, $F(2,188) = 3.79$, $p = .052$, $\eta_p^2 = .04$, $\varepsilon = .53$. Finally, the critical interaction of task type and block type was not significant, $F(2,188) = 0.64$, $p = .475$, $\eta_p^2 = .01$, $\varepsilon = .70$. Thus, dual-task costs were the same in both tasks, and this was not modified by experiment, $F(2,188) = 0.01$, $p = .960$, $\eta_p^2 < .01$, $\varepsilon = .70$, for the second-order interaction.

Discussion

The results mirror those obtained in Experiments 1 and 2, even though forced- and free-choice trials were presented block-wise and not randomly intermingled. Forced-choice responses were about 49 ms faster than free-choice responses. Further, dual-task costs were obtained and, most importantly, these costs were of the same size for the forced- and the free-choice task.

In comparison to Experiment 2, PEs did not differ between forced- and free-choice trials when considering the single- and dual-task blocks. This is important because the single- vs. dual-task comparison was the most important one in the present context, and this result reinforced the suggestion that the RT differences between forced- and free-choice trials were not undermined by trading speed for accuracy in the previous experiment. However, in mixed blocks, more errors were committed in free- than in forced-choice trials, thus again behaving somewhat differently than in the other two block types.

General Discussion

Dual-task costs for forced- and free-choice tasks were measured in three experiments. Forced- and free-choice tasks of this kind have previously been used to operationalize stimulus- and goal-driven actions in a variety of settings. Yet, it is unclear as to how much these types of actions represent distinct classes of actions and one might ask whether they could be better understood as a single kind of behavior. The next section summarizes the main results and relates them to the hypotheses formulated in the "Introduction". This is followed by considering limitations of the present study and relating the study to a recent other study on a similar topic.

Dual-task interference in forced- and free-choice tasks

The empirical results from the three experiments are fairly straightforward. First, in all three experiments, RTs were faster in forced- than in free-choice tasks, thus replicating earlier results (e.g., Berlyne, 1957a). Second, and not surprisingly, dual-task costs were clearly also evident for both tasks. Although mean RTs also increased from single-task to mixed blocks (i.e., mixing costs were observed), a considerably bigger increase from mixed to dual-task blocks was observed (see Figs. 2 and 3). Finally, and most importantly, independent of how mixing and dual-task costs were assessed, these costs were of equivalent size for forced- and free-choice tasks. Note that this conclusion rests on accepting the null-hypothesis of the interaction effect, thus indirectly on a failure to find sufficient evidence for the alternative-hypothesis. First, such failure may result from a lack of statistical power. In the present case, it is difficult to make a reasonable assumption about what effect size can be expected. Note, however, that the experiments were all sensitive enough to consistently find significant effects, for example, the difference in mean RTs between forced- and free-choice tasks. Second, the strength of evidence favoring the null-hypothesis can be calculated with the Bayes factor, from which the posterior

Table 2 Bayes factor (BF) and posterior probabilities for the null-hypothesis (p_{BIC}(H0|D)) and the alternative-hypothesis (p_{BIC}(H1|D)) according to Masson (2011) for the interaction between task type (forced-choice vs. free-choice) and block type (single-task vs. mixed vs. dual-task) in Experiments 1–3

Experiment	*n*	BF	p_{BIC}(H0|D)	p_{BIC}(H1|D)
1	48	27.72	.965	.035
2	48	40.24	.976	.024
3	48	40.84	.976	.024

probabilities for the null- and the alternative-hypothesis can be derived (Masson, 2011; Wagenmakers, 2007). These measures are given in Table 2 and in all three experiments provide strong evidence for the null-hypothesis (Raftery, 1995). One note of caution needs to be made in relation to Experiments 2 and 3. One may argue that the significant interactions for the PE analyses compromise our conclusions somewhat. Please note, however, that the descriptive nature of this interaction was entirely different for both experiments and is thus difficult to interpret. Further, the significant interaction was absent in both experiments when excluding the mixed blocks, thus focusing on dual-task costs.

In sum, we believe that the evidence provides good reasons to conclude that forced- and free-choice tasks are equally susceptible to dual-task interference. First, merely considering the amount of dual-task costs as an empirical marker for the utility of a theoretically made distinction, there is thus no evidence that this distinction is mirrored in differences in empirical data. In other words, according to a dual-task interference criterion there is no need to distinguish two kinds of actions and thus two "action control systems." Second, what do the data mean for the hypotheses put forward in the introduction? The data did not show any signs of additional "control system switch costs" (as illustrated in Fig. 1a) and thus replicate the results of Experiment 3 in Astor-Jack and Haggard (2004).

There are two scenarios that predicted the obtained results: the original account by Berlyne (1957a, b) and the stage-logic based idea that forced- and free-choice tasks have no qualitatively different central stage but differ instead in the duration of their perceptual stages (see Fig. 1b$_1$; see also Janczyk, Dambacher et al., 2014). Given this, it seems not parsimonious to assume that both tasks rely on qualitatively different mechanisms supported by different action control systems. Prinz (1998) has indeed argued that even simple key press responses to stimuli, such as given in forced-choice tasks, must be considered actions (and not reactions): they as well pursue a goal, namely to press a key, and require the formation of an intention. Searle (1980, 1983) distinguished prior intentions and intentions-in-action. A prior intention is typically formed temporally distant from a particular action, and may include "performing the task", "doing what the experimenter desires", and so on. When the particular stimulus appears, however, nothing will happen without an additional intention-in-action that may be caused by the prior intention and itself causes the particular bodily movement.[6] Notably, behavior that is carried out inevitably without the involvement of an intention-in-action is not susceptible to dual-task interference (Janczyk, Pfister, Wallmeier et al., 2014).

One final remark is in order here. Remember that some authors have suggested that two "action control systems" cannot run in parallel (e.g., Astor-Jack & Haggard, 2004). What if one assumes that two "action control systems" exist, both working with their own "independent but each limited capacity"? In this case, a free- and a forced-choice task likely can run in parallel. Note, however, that in this case one would also expect smaller dual-task costs in the case of the free-choice task. This is so, because the concurrent task was always a forced-choice task. Thus, if both tasks were forced-choice they would compete for the same resource, and produce larger dual-task costs compared to the situation where a free- and a forced-choice task do not compete for the same resource.

Limitations of the present study and relations to other studies

Whether or not free- and forced-choice tasks do entail qualitatively different central stages and "action control systems" on the one hand, and whether the longer RTs in free-choice tasks than in forced-choice tasks arise from longer perceptual or central stages on the other hand, are two conceptually independent dimensions. It is important to note, however, that we cannot conclude from the present data whether the RT difference actually arises from the pre-central, perceptual or the central stage of processing. This would require analyses dependent on response order, yet in a large majority of trials participants gave their responses almost simultaneously. In the study by Janczyk, Dambacher et al. (2014) the PRP paradigm (Pashler, 1994) and the locus-of-slack logic (Schweickert, 1978) were used and the results did point to a pre-central, perceptual origin of the RT difference. However, even if one considers both forced- and

[6] Against this background, it should be noted again that the simplified (and theoretical) distinction we have made here by contrasting stimulus- and goal-driven actions does not imply "real", conceptual differences—the interpretation made here even argues against it. Rather, this terminology should only highlight the aspect that determines the accuracy or appropriateness of the emitted action. As both require at least an intention-in-action, the term "intention-based" to characterize *only* actions operationalized by free-choice tasks (Herwig et al., 2007; Keller et al., 2006; Waszak et al., 2005) is thus incomplete and potentially misleading.

free-choice tasks to depend on one and the same "action control system" (implying that no switch is required), the RT difference could also result for other than pre-central, perceptual reasons. For example, to emit possible responses about equally often in a free-choice task, participants need to keep track, at least approximately, of previous responses, and thus the, so-called, "free-choice" task requires storing responses in memory, and retrieving previous responses from memory (or, at least, an approximate count, which has to be updated periodically). Indeed, the same brain areas that have been implicated with "free-choices" are also active during random number generation (Frith, 2013; Jahanshahi, Dirnberger, Fuller, & Frith, 2000).

In our experiments, always two entirely different tasks competed in dual-task blocks and accordingly two responses were given. An interesting study recently investigated the influence of a (forced-choice) stimulus while a free-choice was already being carried out (Devaine, Waszak, & Mamassian, 2013). In this study, participants were to choose between two response options and in between their leaving a (go) key and pressing the chosen response key, a (forced-choice) stimulus was presented. If possible, participants were to take this stimulus into account and to correct their choice. The empirical data show that a certain amount of time for processing the visual forced-choice stimulus was necessary to be taken into account and to increase accuracy. The authors developed a computer model for this data and suggested that they be best explained by the assumption of an internal and an external variable that first accumulate evidence independently from each other and only after a critical amount of time, both enter a "common process" where the external variable influences the internal variable. Thus, this study elegantly addresses how and when environmental information can still influence an already started free-choice response.

At first glance, the finding that both variables in this model accumulate independently and in parallel appears at odd with our assumption of largely serial processing. Given the many differences between the experimental approaches (e.g., two competing tasks in our experiments vs. one task with two competing "sources", …) the reasons remain unclear at present. Future research might develop an experimental paradigm that allows application of the Devaine et al. (2013) model to a dual-task situation and investigate its utility in this case.

Conclusions

We observed equal amounts of dual-task costs for forced- and free-choice tasks across three experiments. According to a dual-task interference criterion then, these results suggest equivalence of previously distinguished types of actions. Also, the results are more in line with the assumption that both task types use the same underlying response selection mechanism instead of being driven by qualitatively different central stages of response selection powered by two different "action control systems."

Acknowledgment This research was funded by the Deutsche Forschungsgemeinschaft (DFG; German Research Council), Project JA 2307/1-1, awarded to Markus Janczyk. We thank Iring Koch and an anonymous reviewer for valuable comments and suggestions on a previous version of this manuscript.

References

Astor-Jack, T., & Haggard, P. (2004). Intention and reactivity. In G. W. Humphreys & J. M. Riddoch (Eds.), *Attention in action: Advances from cognitive neuroscience* (pp. 109–130). Hove: Psychology Press.

Baddeley, A. (2007). *Working memory, thought, and action*. New York, NY: Oxford University Press.

Berlyne, D. E. (1957a). Conflict and choice time. *British Journal of Psychology, 48*, 106–118.

Berlyne, D. E. (1957b). Uncertainty and conflict: A point of contact between information-theory and behavior-theory concepts. *Psychological Review, 64*, 329–339.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624–652.

Brass, M., & Haggard, P. (2008). The what, when, whether model of intentional action. *The Neuroscientist, 14*, 319–325.

Cunnington, R., Windischberger, C., Deecke, L., & Moser, E. (2003). The preparation and readiness for voluntary movement: A highfield event-related fMRI study of the Bereitschafts-BOLD response. *Neuroimage, 20*, 404–412.

Devaine, M., Waszak, F., & Mamassian, P. (2013). Dual process for intentional and reactive decisions. *PLoS Computational Biology, 9*, e1003013. doi:10.1371/journal.pcbi.1003013.

Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 229–240.

Fleming, S. M., Mars, R. B., Gladwin, T. E., & Haggard, P. (2009). When the brain changes its mind: Flexibility of action selection in instructed and free choices. *Cerebral Cortex, 19*, 2352–2360.

Frith, C. (2013). The psychology of volition. *Experimental Brain Research, 229*, 289–299.

Gaschler, R., & Nattkemper, D. (2012). Instructed task demands and utilization of action effect anticipation. *Frontiers in Psychology, 3*, 578. doi:10.3389/fpsyg.2012.00578.

Goldberg, G. (1985). Supplementary motor area structure and function: Review and hypotheses. *Behavioral and Brain Sciences, 8*, 567–588.

Gollwitzer, P. M. (1999). Implementation intentions. Strong effects of simple plans. *American Psychologist, 54*, 493–503.

Halvorson, K. M., Ebner, H., & Hazeltine, E. (2013). Investigating perfect timesharing: The relationship between IM-compatible tasks and dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 413–432.

Harleß, E. (1861). Der Apparat des Willens [The Apparatus of Will]. *Zeitschrift für Philosophie und philosophische Kritik, 38*, 50–73.

Hazeltine, E., Ruthruff, E., & Remington, R. W. (2006). The role of input and output modality pairings in dual-task performance: Evidence for content-dependent central interference. *Cognitive Psychology, 52*, 291–345.

Herbart, J. F. (1825). *Psychologie als Wissenschaft neu gegründet auf Erfahrung, Metaphysik und Mathematik [Psychology as a science newly founded on experience, metaphysics, and mathematics]*. Königsberg: August Wilhelm Unzer.
Herwig, A., Prinz, W., & Waszak, F. (2007). Two modes of sensorimotor integration in intention-based and stimulus-based actions. *Quarterly Journal of Experimental Psychology, 60*, 1540–1554.
Herwig, A., & Waszak, F. (2009). Intention and attention in ideomotor learning. *The Quarterly Journal of Experimental Psychology, 62*, 219–227.
Herwig, A., & Waszak, F. (2012). Action-effect bindings and ideomotor learning in intention- and stimulus-based actions. *Frontiers in Psychology, 3*, 444. doi:10.3389/fpsyg.2012.00444.
Hommel, B. (2000). The prepared reflex: Automaticity and control in stimulus-response translation. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: attention and performance XVIII* (pp. 247–273). Cambridge: MIT Press.
Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849–937.
Hughes, G., Schütz-Bosbach, S., & Waszak, F. (2011). One action system or two? Evidence for common central preparatory mechanisms in voluntary and stimulus-driven actions. *The Journal of Neuroscience, 31*, 16692–16699.
Jahanshahi, M., Dirnberger, G., Fuller, R., & Frith, CD. (2000). The role of the dorsolateral prefrontal cortex in random number generation: A study with positron emission tomography. *Neuroimage*, *12*, 713–725.
Jahanshahi, M., Jenkins, I. H., Brown, R. G., Marsden, C. D., Passingham, R. E., & Brooks, D. J. (1995). Self-initiated versus externally triggered movements. I. An investigation using measurement of regional cerebral blood flow with PET and movement-related potentials in normal and Parkinson's disease subjects. *Brain, 118*, 913–933.
James, W. (1890/1981). *The principles of psychology (vol. 2)*. Cambridge: Harvard University Press.
Janczyk, M. (2013). Level 2 perspective taking entails two processes: Evidence from PRP experiments. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 39*, 1878–1887.
Janczyk, M., Dambacher, M., Bieleke, M., & Gollwitzer, P. M. (2014). The benefit of no choice: Goal-directed plans enhance perceptual processing. *Psychological Research*. doi:10.1007/s00426-014-0549-5.
Janczyk, M., Heinemann, A., & Pfister, R. (2012). Instant attraction: Immediate action-effect bindings occur for both, stimulus- and goal-driven actions. *Frontiers in Psychology, 3*, 446. doi:10.3389/fpsyg.2012.00446.
Janczyk, M., & Kunde, W. (2014). The role of effect grouping in free-choice response selection. *Acta Psychologica, 150*, 49–54.
Janczyk, M., Pfister, R., Crognale, M. A., & Kunde, W. (2012). Effective rotations: Action effects determine the interplay of mental and manual rotations. *Journal of Experimental Psychology: General, 141*, 489–501.
Janczyk, M., Pfister, R., Hommel, B., & Kunde, W. (2014). Who is talking in backward crosstalk? Disentangling response- from goal-conflict in dual-task performance. *Cognition, 132*, 30–43.
Janczyk, M., Pfister, R., & Kunde, W. (2012). On the persistence of tool-based compatibility effects. *Journal of Psychology, 220*, 16–22.
Janczyk, M., Pfister, R., Wallmeier, G., & Kunde, W. (2014). Exceptions to the PRP effect? A comparison of prepared and unconditioned reflexes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 776–786.
Janczyk, M., Skirde, S., Weigelt, M., & Kunde, W. (2009). Visual and tactile action effects determine bimanual coordination performance. *Human Movement Science, 28*, 437–449.
Keller, P. E., Wascher, E., Prinz, W., Waszak, F., Koch, I., & Rosenbaum, D. A. (2006). Differences between intention-based and stimulus-based actions. *Journal of Psychophysiology, 20*, 9–20.
Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., et al. (2010). Control and interference in task switching—A review. *Psychological Bulletin, 136*, 849–874.
Koch, I., Prinz, W., & Allport, A. (2005). Involuntary retrieval in alphabetic-arithmetic tasks: Task-mixing and task-switching costs. *Psychological Research, 69*, 252–261.
Krieghoff, V., Brass, M., Prinz, W., & Waszak, F. (2009). Dissociating what and when of intentional actions. *Frontiers in Human Neuroscience, 3*, 3. doi:10.3389/neuro.09.003.2009.
Kühn, S., Elsner, B., Prinz, W., & Brass, M. (2009). Busy doing nothing: Evidence for nonaction-effect binding. *Psychonomic Bulletin and Review, 16*, 542–549.
Kunde, W. (2001). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 387–394.
Kunde, W., Pfister, R., & Janczyk, M. (2012). The locus of tool-transformation costs. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 703–714.
Logan, G. D., & Gordon, R. D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review, 108*, 393–434.
Lotze, H. R. (1852). *Medicinische Psychologie oder Physiologie der Seele [Medical psychology or the physiology of the mind]*. Leipzig: Weidmann'sche Buchhandlung.
Masson, M. E. J. (2011). A tutorial on a practical Bayesian alternative to null-hypothesis testing. *Behavior Research Methods, 43*, 679–690.
Mattler, U., & Palmer, S. (2012). Time course of free-choice priming effects explained by a simple accumulator model. *Cognition, 123*, 347–360.
Metzker, M., & Dreisbach, G. (2009). Bidirectional priming processes in the Simon task. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1770–1783.
Miller, J., & Reynolds, A. (2003). The locus of redundant-targets and non-targets effects: Evidence from the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 1126–1142.
Miller, J., Rolke, B., & Ulrich, R. (2009). On the optimality of serial and parallel processing in the psychological refractory period paradigm: Effects of the distribution of stimulus onset asynchronies. *Cognitive Psychology, 58*, 273–310.
Müller, V., Brass, M., Waszak, F., & Prinz, W. (2007). The role of the preSMA and the rostral cingulate zone in internally selected actions. *Neuroimage, 37*, 1354–1361.
Nachev, P., & Husain, M. (2010). Action and the fallacy of 'internal': Comment on Passingham et al. *Trends in Cognitive Sciences, 14*, 192–193.
Nachev, P., Kennard, C., & Husain, M. (2008). Functional role of supplementary and pre-supplementary motor areas. *Nature Reviews Neuroscience, 9*, 856–869.
Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language, 55*, 601–626.
Obhi, S. S., & Haggard, P. (2004). Internally and externally triggered actions are physically distinct and independently controlled. *Experimental Brain Research, 156*, 518–523.
Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*, 220–244.
Passingham, R. E., Bengtsson, S. L., & Lau, H. C. (2010a). Medial frontal cortex: From self-generated action to reflection on one's own performance. *Trends in Cognitive Sciences, 14*, 16–21.
Passingham, R. E., Bengtsson, S. L., & Lau, H. C. (2010b). Is it fallacious to talk of self-generated action? Response to Nachev and Husain. *Trends in Cognitive Sciences, 14*, 193–194.

Pfister, R., & Janczyk, M. (2012). Harleß' apparatus of will: 150 years later. *Psychological Research, 76*, 561–565.

Pfister, R., & Janczyk, M. (2013). Confidence intervals for two sample means: Calculation, interpretation, and a few simple rules. *Advances in Cognitive Psychology, 9*, 74–80.

Pfister, R., Kiesel, A., & Hoffmann, J. (2011). Learning at any rate: Action-effect learning for stimulus-based actions. *Psychological Research, 75*, 61–65.

Pfister, R., Kiesel, A., & Melcher, T. (2010). Adaptive control of ideomotor effect anticipations. *Acta Psychologica, 135*, 316–322.

Prinz, W. (1998). Die Reaktion als Willenshandlung [Responses considered as voluntary actions]. *Psychologische Rundschau, 49*, 10–20.

Raftery, A. E. (1995). Bayesian model selection in social research. In P. V. Marsden (Ed.), *Sociological methodology* (pp. 111–196). Cambridge: Blackwell.

Rowe, J. B., Hughes, L., & Nimmo-Smith, L. (2010). Action selection: A race model for selected and non-selected actions distinguishes the contribution of premotor and prefrontal areas. *Neuroimage, 51*, 888–896.

Schüür, F., & Haggard, P. (2011). What are self-generated actions? *Consciousness and Cognition, 20*, 1697–1704.

Schweickert, R. (1978). A critical path generalization of the additive factor method: Analysis of a stroop task. *Journal of Mathematical Psychology, 18*, 105–139.

Searle, J. R. (1980). The intentionality of intention and action. *Cognitive Science, 4*, 47–70.

Searle, J. R. (1983). *Intentionality. An essay in the philosophy of mind*. Cambridge: Cambridge University Press.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276–315.

Stock, A., & Stock, C. (2004). A short history of ideo-motor action. *Psychological Research, 68*, 176–188.

Verleger, R., Jaskowski, P., & Wascher, E. (2005). Evidence for an integrative role of P3b in linking reaction to perception. *Journal of Psychophysiology, 19*, 165–181.

Wagenmakers, E.-J. (2007). A practical solution to the pervasive problems of *p* values. *Psychonomic Bulletin and Review, 14*, 779–804.

Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: Role of episodic S-R-bindings in task-switch costs. *Cognitive Psychology, 46*, 361–413.

Waszak, F., Wascher, E., Keller, P., Koch, I., Aschersleben, G., Rosenbaum, D. A., et al. (2005). Intention-based and stimulus-based mechanisms in action selection. *Experimental Brain Research, 162*, 346–356.

Wiese, H., Stude, P., Nebel, K., de Greiff, A., Forsting, M., Diener, H. C., et al. (2004). Movement preparation in self-initiated versus externally triggered movements: An event-related fMRI-study. *Neuroscience Letters, 371*, 220–225.

Wolfensteller, U., & Ruge, H. (2011). On the timescale of stimulus-based action-effect learning. *Quarterly Journal of Experimental Psychology, 64*, 1273–1289.

Woodworth, R. S. (1938). *Experimental psychology*. New York: Holt, Rinehart and Wilston.