Performance Errors Influence Voluntary Task Choices

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Open practices statement

We have reported all measured variables, conditions, data exclusions, and how we determined our sample sizes. The raw data, commented analysis scripts of all experiments, as well as additional control analyses are available via the Open Science Framework at <https://osf.io/fzd9v/> - DOI 10.17605/OSF.IO/FZD9V.

Abstract

Humans adjust their behavior after they committed an error, but it is unclear whether and how error commissions influence voluntary task choices. In the present article, we review different accounts on effects of errors in the previous trial (transient error effects) and overall error probabilities (sustained error effects) on behavioral adaptation. Based on this review, we derived five statistical models how errors might influence voluntary task choices. We analyzed the data of three experiments in which participants voluntarily selected one of two tasks before each trial whereby task difficulty, and concomitantly error probability, increased successively for the selected/performed tasks. Model comparison suggested that choice behavior was best explained by a combination of error probability of the performed task, error probability of the alternative task, and whether the previous response was correct or incorrect. The results revealed that participants were most likely to switch tasks in situations where the error probability of the performed task was high, the error probability of the alternative task was low, and after an error on the previous trial. We conclude that task selection processes are influenced by transient and sustained error effects.

Keywords: voluntary task switching; cognitive control; error processing; post-error slowing

Public Significance Statements

Humans are constantly faced with the decision to keep engaged with their current task, or to do something else. This research project asked to what extent errors influence this voluntary decision. Results provide evidence that the decision to switch to an alternative task depends not only on the accuracy of the previous trial, but also on the overall error history (i.e., the error probability) of the performed task, and the alternative task. These results extend a large body of literature on error processing in single tasking to situations with multiple tasks available.

Introduction

How do errors influence our behavior? We humans are constantly faced with the option to either keep doing what we are currently doing (e.g., studying mathematics), or to stop this behavior and decide to do something else (e.g., playing video games). One common event which may influence this decision (keep studying vs. playing video games) is the commission of an error during the current task, or even the probability of committing an error during the current task. So far, a large body of literature investigated behavioral changes after the critical event of committing an error when only being faced with one task (Laming, 1968; Rabbitt & Rodgers, 1977; for a review, see Danielmeier & Ullsperger, 2011). Recent modelling work suggested that such changes in task performance (reaction time [RT] and accuracy) that follow after errors should also influence our decision making i.e., whether to continue the focal task or to switch to an alternative task (Musslick et al., 2015; Shenhav et al., 2013). However, behavioral evidence on how errors influence decision making when choosing between multiple tasks is currently not well understood. To close this gap, we investigate how errors that occurred while performing a task influence subsequent task selection processes between multiple tasks.

Post-Error Performance Shifts¹ in Single-Tasking Studies

In single-tasking experiments, errors often lead to slower RTs on the next trial. It has been suggested that this post-error slowing reflects a strategic shift in the response criterion (Laming, 1979). For instance, the conflict monitoring model describes post-error slowing as a change in the speed-accuracy tradeoff (Botvinick et al., 2001). More specifically, in this model, errors are treated

¹ Please note that we use the neutral term “shift” instead of adjustment or adaptation because errors might result in adaptive but also in maladaptive changes of performance.

as a special case of conflict between mutual incompatible responses². It is assumed that conflict is registered by a monitoring system and that the strength of conflict informs recruitment of control in subsequent trials (Maier et al., 2011). Furthermore, increased control should bias responding towards a more conservative threshold. Such a shift in the response decision criterion results in slower and more accurate responses following errors. This idea received further support from formal modeling approaches which used evidence accumulator models to show that performance following errors reveals a change in the response threshold (Dutilh et al., 2012; Purcell & Kiani, 2016) and from empirical studies showing improved accuracy after an error (Danielmeier et al., 2011; Laming, 1968; Marco-Pallarés et al., 2008). In the following, we use the term “transient error effects” to account for the influence of a single error event on subsequent behavior.

Yet, errors often do not occur in isolation. While in some contexts, errors are single events, for instance due to attentional lapses, in other contexts, errors are overall more frequent. These sustained error effects (i.e., error probability) can modulate post-error performance shifts. This was illustrated in a study by Notebaert and colleagues (2009) who manipulated task difficulty and reported larger post-error slowing in the condition with low error probabilities relative to medium error probabilities. Interestingly, the opposite effect of slower responses after accurate compared to erroneous responses was observed in the condition with high error probabilities. This later finding contradicts the adaptive conflict monitoring account and rather supposes the existence of maladaptive effects of error processing. Maladaptive effects indicate that post-error slowing does not (always) *improve* behavior due to cognitive control adaptations after errors but rather suggests

² While conflict during correct trials should be highest before response execution (i.e., before the correct response is selected), conflict in trials with incorrect responses should be highest after response execution, because of the conflict between the incorrect response and a tendency to correct the produced response (see Yeung et al., 2004).

the possibility of *impaired* processing after errors. Studies from other research groups supported this maladaptive account on error processing but suggested different mechanisms on why error processing may not be adaptive. For instance Wessel and Aron (2017) suggested that impairments after errors are due to a global stopping response caused by unexpected error events (Wessel & Aron, 2017), whereas Jentsch and Dudschig (2009) suggested capacity limitations due to a bottleneck which arises when not enough time is provided between trials and error monitoring processes interfere with post-error stimulus encoding (Jentsch & Dudschig, 2009).

This reduced post-error slowing effect with increasing error probabilities can be explained by the PRO model (Alexander & Brown, 2011; but see Notebaert et al., 2009). This model suggests a monitoring system which registers the difference between expected and actual outcomes. As a consequence, this comparison yields a smaller control signal and consequently reduced post-error slowing for errors that occur in an environment with overall high error probability compared to an environment with an overall low error probability (see Jessup et al., 2010). While these studies seek to explain the diverse findings of post-error performance shifts, they lack a direct test in how performance errors influence task choices in situations with multiple tasks available.

In sum, the theories described above aimed to explain how errors induce performance adjustments on the following trial in single-tasking experiments. These theories distinguish between (a) transient error effects (i.e., the impact of a single error event on the following trial), (b) sustained error effects (i.e., the impact of overall error probabilities on the following trial), or (c) the combination of transient and sustained effects (e.g., effects of single errors on the following trial depend on error probabilities). However, the theories reviewed so far focused on performance shifts after errors and did not address whether errors influence task choices. In the following

section, we review research which addressed the influence of errors on task choices in voluntary task switching settings, with a specific focus on transient and sustained effects of errors.

Post-Error Shifts in Task Choices

In situations with multiple tasks available, errors during task performance might have an impact on the task selection process. First evidence comes from the voluntary task switching paradigm that requires participants to select tasks randomly by mentally flipping a coin that indicates which task to perform next (Arrington & Logan, 2004). Arrington and Logan (2004) found that participants' switch rate was less than the 50% expected for random choices and referred to this as the repetition bias (Arrington & Logan, 2005; Dignath et al., 2015; Yeung, 2010). Using this paradigm, Orr et al. (2012) investigated whether the repetition bias in voluntary task switches would be further modulated by errors on the previous trial, compared to accurate responses on the previous trial. They found that errors in the previous trial (i.e., transient error effects) biased task choices towards more task repetitions compared to previous correct trials. One interpretation, advanced by Orr and colleagues (2012), argues that increased post-error control amplifies the previously performed task set, rendering it thereby more available for task selection (see Brown et al., 2006; Goschke, 2000). However, an alternative interpretation, based on the observation that random task selection requires central resources, suggests that error monitoring occupies resources which then impairs the ability to select tasks randomly (Arrington & Logan, 2005; Jentsch & Dudschig, 2009).

While Orr and colleagues (2012) focused on the potential of transient errors to modulate task choice, other research focused on sustained error effects (i.e., error probabilities) on task choices. For example, Kool and colleagues (2010) provided evidence that participants select task

contexts associated with low error probabilities more often than task contexts associated with high error probabilities, suggesting that participants anticipate both the effort associated with the probability of errors when repeating tasks and the effort associated with the probability of errors of the alternative task (Botvinick, 2007; Kurzban et al., 2013; Shenhav et al., 2017). Further evidence that sustained error effects influence task selection processes comes from a study of Wisniewski and colleagues (2015) who investigated task rule selection as a function of task difficulty, in terms of error rates and RTs (Wisniewski et al., 2015). On each trial, participants were allowed to choose between one of three different response rules to categorize an object, before actually performing the object categorization task. When repetitively selecting the same response rule, the difficulty of the selected task increased while the difficulty of the non-selected tasks decreased. Results indicate that participants were more likely to switch the response rule and choose one of the other two alternative response rules with increasing task difficulty. Thus, these results suggest that participants' rule switching behavior was not only influenced by sustained error effects but also that participants kept track of the difficulty of the other two alternative tasks and traded-off the difficulty of these two alternative rule choices with the rule choice on the previous trial. Together, these studies propose that not only the costs and benefits associated with the performed task but also the costs and benefits associated with the alternative task are considered when exposed to multiple tasks.

A view that allows theoretical predictions based on the combination of transient and sustained error effect is the Expected Value of Control (EVC) theory (Musslick et al., 2015; Shenhav et al., 2013). This theory aims to explain human decision making as a function of a cost-benefit analysis which integrates performance costs associated with a task and rewards associated with a task within one value – namely the expected value of control. Task decisions are then based

on the task associated with the highest expected value of the described analysis. More precisely, a joint utility function considers the overall pay-off that can be anticipated from selecting a control signal, weighting the costs (in terms of control demands) of implementing cognitive control towards each potential task as well as the potential costs (in terms of control demands) in case of reconfiguring cognitive control towards another task (i.e., when switching tasks) against the benefits (i.e., rewards) associated with each task option. This cost-benefit trade-off perspective suggests that demands in cognitive control influence task selection processes and thus, it predicts that demands from transient error effects and sustained error effects for all potential tasks influence task selection processes.

Predictions on how Errors Influence Task Choices

Following the work reviewed above, we sought to investigate whether task choices are based on (a) transient error effects, (b) the error probability of the just performed task, (c) the error probability of the just performed task and the error probability of the alternative task, (d) transient error effects and the error probability of the just performed task, or (e) transient error effects and the error probability of the just performed task and the error probability of the alternative task. In the following sections we labeled transient error effects as *error_{n-1}*, the error probability of the task performed in trial n-1, i.e., before the task selection, as *error probability of the performed task*, and the error probability of the alternative (not performed) task in trial n-1 as *error probability of the alternative task*. We formalized task choices with five distinct logistic mixed-model regressions that predict the probability to switch to the alternative task in the following trial (in n) to examine which of these models fitted the data of three conducted experiments best.

More specifically, findings from the voluntary task switching literature (Orr et al., 2012) suggested that task choices depend on transient error effects, with low switch rates after erroneous responses compared to accurate responses. Model 1 was derived from these findings and was formalized as:

$$\ln[P(\text{alternative task choice})/1 - P(\text{alternative task choice})] = \beta_0 + \beta_1 X_1 \quad (1),$$

where X_1 is *error_{n-1}*.

The demand avoidance literature (Botvinick, 2007; Dunn et al., 2019; Kool et al., 2010; Westbrook et al., 2013; Westbrook & Braver, 2015; Wisniewski et al., 2015) suggested that task choices depend on sustained error effects. In contrast to the finding by Orr and colleagues (2012), this line of research suggests increased switch rates of tasks associated with high error probabilities compared to tasks with low error probabilities. While these studies suggest that participants choose tasks with low demand, it is unclear whether the selection process only incorporates the error probability of the performed task or whether it incorporates the error probability of the performed task and the error probability of the alternative. A direct test can be conducted by comparing the fit of both models with each other. Thus, we formalized these two predictions with two distinct models as:

$$\ln[P(\text{alternative task choice})/1 - P(\text{alternative task choice})] = \beta_0 + \beta_1 X_1 \quad (2),$$

where X_1 = *error probability of the performed task*;

$$\ln[P(\text{alternative task choice})/1 - P(\text{alternative task choice})] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 \quad (3),$$

where X_1 = *error probability of the performed task* and X_2 = *error probability of the alternative task*.

Previous research found an interaction between transient error effects and sustained error effects (Notebaert et al., 2009), which suggested that task choices depend on both transient error effects and sustained error effects, with increased switch rates after erroneous compared to accurate responses for lower error probabilities of the performed task, but relatively decreased switch rates after erroneous compared to accurate responses for higher error probabilities of the performed task. Model 4 captures both error terms – errors on the previous trial and error probabilities of the performed task – including the interaction of the two terms:

$$\ln[P(\text{alternative task choice})/1 - P(\text{alternative task choice})] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 \quad (4),$$

where X_1 = *error_{n-1}* and X_2 = *error probability of the performed task*.

Finally, the EVC theory (Shenhav et al., 2013) suggests that task choices depend on a cost-benefit analysis of possible control implementations. More precisely, the EVC theory suggests that control is adaptive and scales with current demands on a trial-by-trial basis. This indicates that the amount of control allocated towards one task gradually shifts with the performance on this task. Even though the overall error probability of a task determines the amount of control needed, single erroneous responses also lead to shifts in the control intensity, and thus lead to control adjustments. Accordingly, transient errors should signal increased control demands for the next trial in addition

to the control demands associated with the error probability of the currently performed and the alternative task. We formalized this prediction as:

$$\ln[P(\text{alternative task choice})/1 - P(\text{alternative task choice})] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 \quad (5),$$

where $X_1 = \text{error}_{n-1}$, $X_2 = \text{error probability of the performed task}$, and $X_3 = \text{error probability of the alternative task}$.

The Present Research

To test these models, we conducted three experiments in which participants had to repeatedly select one of two perceptual decisions tasks – a color discrimination task and a motion discrimination task (for a previous study using these two tasks see Spitzer et al., 2019) - and subsequently performed the selected task. For each task, 200 dots were shown on the screen and participants either had to detect whether the majority of dots were presented in red or blue (color discrimination task) or were moving upwards or downwards (motion discrimination task). We made use of these two tasks since the error probabilities of each task can be easily varied by manipulating the signal to noise ratio without varying the task identity³ (Spitzer et al., 2019; Strittmatter et al., 2021). In Experiment 1a and 1b, trial-by-trial error feedback was provided, while Experiment 2 generalized findings to a situation with no feedback presented. Based on previous findings we speculated that participants would recognize errors without feedback (e.g., Di

³ A major advantage of applying the dot motion task is that coherence changes of the task lead to higher or lower error rates and/or RTs on the task, but the task identity itself (i.e., discriminating whether dots move up or down remains the same) remains the same.

Gregorio et al., 2020) and that perceived errors without feedback would lead to similar post-error shifts as errors with feedback (Nieuwenhuis et al., 2001; Wessel et al., 2011).

To manipulate the error probability of each task, respectively, the signal to noise ratio of the performed task was gradually decreased (after 6-9 trials). In contrast, the signal to noise ratio of the alternative (not performed) task remained on the same level (see Figure 1).

We recorded participants' task choices on each trial. In contrast to previous voluntary task switching studies (Arrington, 2008; Arrington & Logan, 2004, 2005; Liefoghe et al., 2009), we did not provide participants with any instructions on how often to choose each task or to aim for random task choices (Brüning et al., 2020; Brüning & Manzey, 2018; Mayr & Bell, 2006; Mittelstädt et al., 2017, 2018, 2019; Monno et al., 2021; Yeung, 2010). Thus, participants were allowed to freely choose which of the two tasks to engage with before each trial. In addition to the statistical model comparison for task choices, we fitted the same statistical models for task choice latencies (i.e., RTs when participants select a task) to investigate which of the five described models explain task choice latencies best and to investigate how transient and/or sustained errors influence task choice latencies. For completeness, task performance measures (RT and accuracy) for the winning task choice model are reported in the supplement material.

Experiment 1

Experiment 1a

Experiment 1a tested how performance errors influence task selection processes. More precisely, we were specifically interested in whether (a) *error_{n-1}*, (b) *the error probability of the performed task*, (c) *the error probability of the alternative task*, (d) a combination of (a) and (b), or (e) a combination of all three factors influenced participants' voluntary task choices (in n).

Methods

Participants

Fifty-eight participants (44 females; $M_{age} = 23.9$; $SD_{age} = 3.7$) took part in the experiment. All participants were right-handed and had normal or corrected to normal vision. Participants signed an informed consent form before the start of the experiments and received 8 Euros for their participation. Experiment 1a was the first time that this paradigm was applied. The sample size was originally estimated with the GPower3 program (Faul et al., 2007) and suggested that at least 34 participants would be sufficient for moderate effects with a medium effect size of $d = .5$ (that is for t-tests with two dependent means when setting alpha error to .05 and power to 80%). Even though effect sizes are differently described with logistic mixed models, we assumed that a sample size of >34 should be sufficient. We then collected data of as many participants as we could (at least 34 participants) within the first month of the semester and ended up with the sample size of 58. After we collected the data, we additionally simulated post-hoc power analyses for each significant effect of the winning task choice model using the *simr* package in *r* (Green & Macleod, 2016). Each power analysis was based on 100 simulations. The first power simulation on the significant effect of *alternative error probability* with an effect size (beta) of -6.88 and an alpha level of 0.05, revealed a power of 100% with a 95% -confidence interval (95%-CI) between 94-100%. A second power simulation on the significant interaction of *error_{n-1}* and *error probability of the performed task* with an effect size (beta) of 0.72, and an alpha level of 0.05, revealed a power of 68% (95%-CI = 54-81%). A third power simulation on the significant interaction effect of *error probability of the performed task* and *alternative error probability* with an effect size (beta) of 3.85 and an alpha level of 0.05, revealed a power of 92% (95%-CI = 81-98%). Finally, a fourth

simulation on the significant three-way interaction effect with an effect size (beta) of -2.04, and alpha level of 0.05, revealed a power of 63% (95%-CI = 53-73%).

Apparatus and Stimuli

The stimulus and task were administered with the jsPsych software (de Leeuw, 2015) running on a Fujitsu EPrimo P920 computer and a Iiyama prolife gb2488hsu monitor. All stimuli were presented on a grey background on a 24-in. screen with a refresh rate of 144 Hz and a resolution of 1920x1080. Each stimulus was a random-dot motion kinematogram task implemented with the rdk-plugin (Rajananda et al., 2018; but also see Strittmatter et al., 2021), with 200 dots, the dot size set to 2, and the moving distance set to 0.6. In the color task, the dots were colored in blue and red ink. In the motion task the dots were colored in black ink.

Procedure

Each trial consisted of the following sequence: task selection, followed by a fixation cross, a color or motion random-dot kinematogram stimulus, and response contingent feedback (see Figure 2). During the task selection phase, participants had to select one of two tasks: a motion direction discrimination task with the response button “A” (left ring finger) or a color discrimination task with the response button “L” (right ring finger) on a QWERTZ keyboard. Participants were given 5000ms to select one of the two tasks. If no task was selected within this time window, the previous task was selected automatically. These trials were excluded before analyzing the data. If no task was selected at the very beginning of the experiment, a task was automatically selected in random order. After the task selection, a fixation cross appeared for 701ms, followed by the stimulus presentation.

During the motion task, randomly moving black colored dots were presented while a proportion of dots moved coherently in either an upward or downward direction. Participants had

to respond to the direction of coherent motion using the response buttons “S” (more up; left middle finger) and “D” (more down; left index finger). During the color task, randomly moving dots were colored in red and blue ink, with one color being more dominant compared to the other color (e.g., 65% of the dots were colored in blue while 35% of the dots were colored in red). Participants had to respond to the color of the majority of the dots using the response buttons “J” (more blue; right index finger) and “K” (more red; right middle finger). Stimuli (size of perceptual angle approximately 33°) were presented for 1000ms or until a response key was pressed. A correct trial ended with a feedback screen (“Correct”) for 701ms. In case of an incorrect or late response (within a response window of 1000ms after target onset), error feedback (“Incorrect”) was presented for 701ms. Responses before the onset of the stimulus were not recorded. Participants were told that the difficulty of the performed task would eventually increase while the difficulty of the alternative task would not increase and they were not provided with any instructions how often to select each task (Brüning et al., 2020; Brüning & Manzey, 2018; Mittelstädt et al., 2017, 2018, 2019; Monno et al., 2021). Participants were instructed to respond as fast and accurate as possible on each trial.

Participants started with 13 practice trials. The main experiment consisted of ten blocks with 80 trials each, with self-paced breaks between the blocks.

To manipulate error probabilities for each task, we reduced the signal to noise ratio of the performed task every six to nine trials (with 25% probability for the sixth to ninth trial). For the color task we selected 65%, 62%, 59%, 56%, 53%, and 50% as the six signal to noise ratio levels indicating the proportion of the dominant color for each signal to noise ratio (no dominant color at the 50% condition). For the motion task we selected 30%, 24%, 18%, 12%, 6%, and 0% as the six signal to noise ratios indicating the proportion of dots moving in the target direction. These signal to noise ratios were selected based on previous research with this task (Spitzer et al., 2019). At the

beginning of each block, the color task started with a signal to noise ratio of 65% and the motion task started with a signal to noise ratio of 30%. An example sequence is illustrated in Figure 1 and an example trial is shown in Figure 2.

Data Analysis

The main analysis investigated how errors influence task choices. From an experimental standpoint, errors cannot be manipulated directly, but different signal to noise ratios make errors more or less likely. Thus, we measured the three variables *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* and treated these measurements as predictor variables to predict task choices. Omission errors and early responses were not included. The first predictor variable *error_{n-1}* indicated whether the trial before task choice was correct or incorrect. Error probabilities were computed as follows: the error probability of the performed task and the error probability of the alternative task were computed as the average error probability for repetition trials⁴ for each participant, each task, and each signal to noise ratio level, respectively. If the derived empirical error probabilities exceeded 50% for a participant in any condition, we set this error probability to 50%. For task choices and for task choice latencies, the error probability of the performed task indicated the error probability of the performed task before the task choice while the error probability of the alternative task indicated the error probability of the alternative task before the task choice. For the two performance measures RT and accuracy, the *error probability* indicated the error probability associated with the task these performance measures came from, while the *alternative error probability* indicated the error probability associated with the non-performed task.

⁴ Switch trials were excluded due to switch costs in terms of higher error rates on these trials.

We first asked which of the predictor variables or combination of predictor variables of $error_{n-1}$, *error probability of the performed task*, or *error probability of the alternative task* explained task choice and task choice latencies best, respectively. We computed the log likelihood as an indicator for the goodness of fit for each model, with the log likelihoods closer to zero indicating better model fits. Based on a reviewers' recommendation, we additionally computed the Bayesian information criterion (BIC) for the goodness of fit for each model, with smaller BIC indicating better model fits. The BIC penalizes model complexity, especially for small sample sizes (Burnham & Anderson, 2002). The outcome of the model with the best fit (with respect to log likelihood and BIC) is described in the results section. If log likelihood and BIC indicated a different winning model, we computed an ANOVA between the two models to indicate which of the two models fitted the data significantly better. In addition, we used the winning model to explain performance data (RT and accuracy). Please note that we added the factor *task transition* (switch vs. repeat) which served as the dependent variable for task choices as an additional factor to the model for performance data to account for the influence of task switches versus task repetitions on performance.

For the winning model, we estimated effects with a hierarchical logistic regression for binary dependent variables (task choices and accuracy) using the lme4 package (Bates et al., 2014) in the R environment for statistical computing (version 3.4.4, 64-bit build; R Core Team, 2015). Continuous dependent variables (task choice latencies and RT) were estimated with the lmerTest package (Kuznetsova et al., 2017). Degrees of freedom were approximated with Satterthwaite's method (Satterthwaite, 1946). Data was analyzed with hierarchical models as they are less vulnerable to Type 1 errors compared to analysis of variance (Judd et al., 2017; Quené, 2008; Quené & Van Den Bergh, 2004). Plots were generated with the sjPlot package (Lüdtke,

2020). The random effects structure was selected based on the most complex model with no singularity in the random effect terms (Bates et al., 2015) and the best model fit compared to other model formula possibilities (Bates et al., 2015). However, we did not include interaction terms in the random effect structure, due to unfeasible long computation times. We report estimates, t-values (for linear mixed model results), or z-values (for logistical mixed model results) and p-values of the fixed effects of the hierarchical models (see the supplement material for random effects results). The intercept reports the grand average of the participants. The estimate reports the deviation of this estimate with regards to the effect in the direction of the effect. The estimate multiplied with -1 computes the effect with regards to the opposite direction. The deviation of the grand mean in the positive direction plus the negative direction of the estimate computes the effect of a factor.

Results

We used the same exclusion criteria for all dependent variables: We excluded the first trial of each block, all trials and the following trials with an RT of 200ms or faster, or when participants did not respond within the 1000ms window (16.51%). Only for performance RT analyses, we additionally excluded all incorrect responses (30.68%). The manipulation of decreases in the signal to noise ratio to increase error rates was successful (see Figure 3). The influence of decreases in the signal to noise ratio on RTs are depicted in S1.

Task Choices

The model comparison revealed that Model 5 (which included the three variables *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task*) fitted the data best (see Table 1). The random effect structure comprised a random slope for each main effect of

the three independent variables and a random intercept for participants. Please note that this random effect structure was neither too simple, nor too complex and should thus achieve high power without an inflated Type I error rate (Matuschek et al., 2017)⁵. The influence of these three variables on the probability to switch to the alternative task are depicted in Figure 4. We report main effects as well as significant interaction effects of Model 5 in the following section (see Table 2 for all results of Model 5).

The main effect *error_{n-1}* was not significant ($b = 0.11$; $z = 0.75$; $p = .447$). The main effect *error probability of the performed task* was not significant ($b = 0.21$; $z = 0.43$; $p = .661$). The main effect *error probability of the alternative task* was significant ($b = -6.88$; $z = -9.51$; $p < .001$) with a larger probability to switch to the alternative task when the error probability of the alternative task was smaller. The two-way interaction of *error_{n-1}* and *error probability of the performed task* was significant ($b = 0.71$; $z = 2.10$; $p = .035$) with an increased switch probability after an error, compared to a correct response, but only if the error probability of the performed task was high. The two-way interaction of *error probability of the performed task* and *error probability of the*

⁵ We also inspected the model fits of two other random effect structures (only a random intercept and an additional random effect of block nested within the random effect of participant) and the fit of a model which included the predictor *last task* as main effect and interaction effect with all other variables to examine the robustness of the reported results of the winning model. In particular, the random effects were (1 |subject_id) and (*error_{n-1}* + *error probability of the performed task* + *error probability of the alternative task* |subject_id/block) for the two alternative random effect structure models. The fixed effect result pattern of these models mimicked the result pattern of the selected model. However, when only fitting a random intercept for participants and when adding a nested random intercept for block, the two-way interaction of *error_{n-1}* and *error probability of the performed task* (1 |subject: $b = 0.40$; $z = 1.30$; $p = .192$; *error_{n-1}* + *error probability of the performed task* + *error probability of the alternative task* |subject_id/block: $b = 0.70$; $z = 1.86$; $p = .062$) as well as the three-way interaction fell short of significance (1 |subject: $b = -1.43$; $z = -1.51$; $p = .131$; *error_{n-1}* + *error probability of the performed task* + *error probability of the alternative task* |subject_id/block: $b = -2.22$; $z = -1.94$; $p = .051$). Results replicated for the model which included the predictor *last task*.

alternative task was significant ($b = 3.85$; $z = 3.40$; $p < .001$) with an increased probability to switch to the alternative task when the error probability for the performed task was higher and the error probability of the alternative task was lower. The three-way interaction *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* was significant ($b = -2.04$; $z = -1.98$; $p = .047$) with an increased probability to switch to the alternative task after an error, compared to a correct response, but only when the just performed task was associated with high error probability and when the alternative task was associated with low error probabilities (see Figure 4).

Task Choice Latency

In line with task choices, the model comparison revealed that Model 5 (including the additional factor *task transition*) fitted the task choice latencies data best (see Table 3). Please note that the additional factor task transition was included in all models. The random effect structure comprised a random slope for *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task*, but not for *task transition* and a random intercept for participants. The influence of the three factors *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* on task choice latencies are depicted in Figure 5, for repetition trials, and Figure 6, for switch trials. We report the results of all main effects and all significant interactions of this winning model in the following section. The full results of task choice latencies are described in Table 4.

The main effect of *error_{n-1}* was significant ($b = 121.91$; $t(13108) = 6.64$; $p < .001$) with 122ms slower choices after errors than accurate responses (post-error slowing). The main effect of *error probability of the performed task* was significant ($b = -265.42$; $t(2224) = -4.82$; $p < .001$) with 3ms faster task choices with each percent increase in error probability of the performed task.

The main effect of *error probability of the alternative task* was significant ($b = -339.77$; $t(375) = -4.74$; $p < .001$) with 3ms faster choices with each percent increase in error probability of the alternative task. The main effect of *task transition* was significant ($b = 225.53$; $t(106) = 6.59$; $p < .001$) with 226ms slower task choice latencies on task switch choices than task repetition choices. The two-way interaction of $error_{n-1}$ and *error probability of the performed task* was significant ($b = -294.79$; $t(32802) = -5.83$; $p < .001$) with post-error slowing on task choice latencies when the error probability of the just performed task was low, but not when it was high. The two-way interaction of $error_{n-1}$ and *error probability of the alternative task* was significant ($b = -164.54$; $t(34450) = -2.85$; $p = .004$) with post-error slowing on task choice latencies when the alternative error probability was low but decreasing post-error slowing with increasing alternative error probability. The two-way interaction of $error_{n-1}$ and *task transition* was significant ($b = 59.17$; $t(28609) = 3.27$; $p = .001$) with an increased post-error slowing effect on switch trials compared to repetition trials. The two-way interaction of *error probability of the performed task* and *error probability of the alternative task* was significant ($b = 342.27$; $t(165) = 2.07$; $p = .038$) with a steeper decrease of choice latency with increasing error probability of the performed task when also the error probability of the alternative task increased. The three-way interaction of $error_{n-1}$, *error probability of the performed task*, and *error probability of the alternative task* was significant ($b = 517.18$; $t(33178) = 3.32$; $p < .001$). After errors, compared to correct responses, the reduction in task choice latencies was steeper with increasing error probability of the performed task and with increasing error probability of the alternative task compared to lower error probabilities of the alternative task. The three-way interaction of $error_{n-1}$, *error probability of the performed task*, and *task transition* was significant ($b = -147.01$; $t(33531) = -2.92$; $p = .003$) with increased task choice latencies after errors compared to correct trials on repetition trials, but this difference

decreased with increasing error probabilities of the performed task for repetition trials. For switch trials, in contrast, the difference between task choice latencies after errors compared to correct responses increased with increasing error probability of the performed task.

Experiment 1b

In this experiment, we were interested to (a) replicate the findings of Experiment 1a and (b) investigate whether exposing participants to a broader range of lower error probabilities would show the same results as in Experiment 1a. Therefore, we applied eight different levels of signal to noise ratio for each task.

Methods

Participants

Forty-six students (37 female; $M_{age} = 23.4$; $SD_{age} = 3.8$) from the University of Freiburg, Germany performed the experiment and received 8 Euros for their participation. We did not exclude data of any participants. None of the participants performed Experiment 1a. The sample size was based on the G*power estimation of Experiment 1a with a minimum of 34 participants. We allowed all participants who signed up for the study within one month to participate in this study and collected their data or until the minimum number of 34 participants was reached. We additionally simulated post-hoc power analyses on the significant results of this experiment. Each power analysis was based on 100 simulations. The first power simulation on the significant effect of *error probability of the performed task* with an effect size (beta) of 1.66 and an alpha level of 0.05, revealed a power of 90% (95%-CI = 78-97%). A second power simulation on the significant *alternative error probability* effect with an effect size (beta) of -8.46 and an alpha level of 0.05,

revealed a power of 100% (95%-CI = 97-100%). A third simulation on the interaction effect of *error_{n-1}* and *alternative error probability* with an effect size (beta) of 0.85, and alpha level of 0.05, revealed a power of 50% (95%-CI = 36-64%). Finally, a fourth simulation on the significant interaction of *error probability of the performed task* and *alternative error probability* with an effect size (beta) of 6.12, and an alpha level of 0.05, revealed a power of 100% (95%-CI = 93-100%).

Stimulus, Procedure, and Data Analysis

Participants were exposed with the same voluntary task switching paradigm as in Experiment 1a. However, we manipulated the signal to noise ratio settings in the following way. For the motion task, the signal to noise ratio started at 48% of dots moving in the same direction and decreased in 6% increments to the levels 48%, 42%, 36%, 30%, 24%, 18%, 12 % and 6% for the levels 1 to 8, respectively. For the color task, the signal to noise ratio started at 74% of the dominant color and decreased in 3% increments to the levels 74%, 71%, 68%, 65%, 62%, 59%, 56%, and 53% for the respective level. The data analysis followed the same procedure as Experiment 1a.

As in Experiment 1a, participants started with 13 practice trials. Due to the increased number of signal to noise ratio levels, the main experiment consisted of seven blocks with 130 trials each, with self-paced breaks between the blocks.

Results

The same exclusion criteria as in Experiment 1a were applied. We excluded the first trial of each block and all trials with response times below 200ms or if no response was given (11.47%).

Only for the RT analysis incorrect trials were excluded (21.89%). The influence of signal to noise ratio decreases on error rates and RTs are plotted in S1 and S2, respectively.

Task Choices

As in Experiment 1a, Model 5 fitted the data best (see Table 1). Figure 4 depicts the influence of the three predictor variables on the probability to switch to the alternative task. The random effect structure comprised a random slope for each main effect and a random intercept for participants⁶. All results are listed in Table 2. Main effects and significant interactions are described in the following section. The manipulation of decreases in the signal to noise ratio to increase error rates was successful (see Figure 3). The influence of decreases in the signal to noise ratio on reaction times are depicted in S1.

As in Experiment 1a, the main effect $error_{n-1}$ was not significant ($b = 0.23$; $z = 1.52$; $p = .126$). In line with Experiment 1a, the main effect of *error probability of the performed task* was significant ($b = 1.66$; $z = 3.09$; $p = .001$) with higher switch rates on larger error probabilities on the performed task. In line with Experiment 1a, the main effect *error probability of the alternative task* was significant ($b = -8.46$; $z = -8.10$; $p < .001$) with a decreased probability to switch to the alternative task when its error probability was high. The two-way interaction of $error_{n-1}$ and *error probability of the alternative task* was significant ($b = 0.85$; $z = 1.99$; $p = .045$) with a higher probability to switch to the alternative task after an error on the previous trial when this alternative task was associated with low error probabilities. The two-way interaction of *error probability of the performed task* and *error probability of the alternative task* was significant and replicated the result of Experiment 1a ($b = 6.12$; $z = 4.27$; $p < .001$) with a higher probability to switch to the

⁶ The results were the same for the two alternative random effect structure models (1 |subject_id) and ($error_{n-1} + error\ probability\ of\ the\ performed\ task + error\ probability\ of\ the\ alternative\ task$ |subject_id/block). Results also replicated for the model which included the predictor *last task*.

alternative task when this task was associated with a low error probability and when the error probability of the performed task was high.

Task Choice Latency

BIC suggested that Model 3 fitted the data best, and log likelihoods suggested that Model 5 fitted the data best (see Table 3). We thus computed an ANOVA comparing these two models which suggested that Model 5 significantly fitted the data best ($p < .001$). The influence of the three factors *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* variables on task choice latencies are depicted separately for repetition trials in Figure 5 and for switch trials in Figure 6. We report the results of all main effects and all significant interactions of this winning model in the following section. The random effect structure comprised a random slope for *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task*, but not for *task transition* and a random intercept for participants. The full results of task choice latencies are described in Table 4.

The main effect of *error_{n-1}* was significant ($b = 59.93$; $t(1752) = 4.74$; $p < .001$) with 60ms slower choices after errors than accurate responses (post-error slowing). The main effect of *error probability of the performed task* was significant ($b = -159.10$; $t(453) = -3.15$; $p = .001$) with 2ms faster task choices with each percent increase in error probability of the performed task. The main effect of *error probability of the alternative task* was significant ($b = -166.86$; $t(336) = -3.01$; $p = .002$) with 3ms faster task choices with each percent increase in error probability of the alternative task. The main effect of *task transition* was significant ($b = 278.71$; $t(49) = 5.56$; $p < .001$) with 279ms slower task choice latencies on switch trials than repetition trials. The two-way interaction of *error_{n-1}* and *error probability of the alternative task* was significant ($b = -172.96$; $t(3843) = -4.10$; $p < .001$) with post-error slowing when the error probability of the alternative task was low

but not when it was high. The two-way interaction of $error_{n-1}$ and *task transition* was significant ($b = 42.72$; $t(15776) = 3.55$; $p < .001$) with post-error slowing on repetition trials but no post-error slowing on switch trials. The two-way interaction of *error probability of the performed task* and *task transition* was significant ($b = -136.62$; $t(6468) = -3.08$; $p = .002$). On increasing error probabilities of the performed task switch costs were higher. The two-way interaction of *error probability of the alternative task* and *task transition* was significant ($b = -111.76$; $t(4425) = -2.24$; $p = .025$). On increasing error probabilities of the alternative task switch costs were higher. The three-way interaction of $error_{n-1}$, *error probability of the performed task*, and *error probability of the alternative task* was significant ($b = 432.39$; $t(3237) = 2.93$; $p = .003$). After errors, compared to correct responses, the reduction in task choice latencies was steeper with increasing error probability of the performed task and with increasing error probability of the alternative task compared to lower error probabilities of the alternative task. The three-way interaction of $error_{n-1}$, *error probability of the performed task*, and *task transition* was significant ($b = -125.83$; $t(9620) = -3.16$; $p = .001$) with increased task choice latencies after errors compared to correct trials on repetition trials, but this difference decreased with increasing error probabilities of the performed task for repetition trials. For switch trials, in contrast, the difference between task choice latencies after errors compared to correct responses increased with increasing error probability of the performed task. The three-way interaction of $error_{n-1}$, *error probability of the alternative task*, and *task transition* was significant ($b = -167.78$; $t(4231) = -4.01$; $p < .001$) with increased task choice latencies after errors compared to correct trials on repetition trials, irrespective of the error probability of the alternative task. On switch trials, task choice latencies increased after errors compared to correct responses, but only on low alternative error probabilities. With increasing alternative error probabilities participants revealed faster task choice latencies after errors

compared to correct trials. The three-way interaction of *error probability of the performed task*, *error probability of the alternative task*, and *task transition* was significant ($b = 432.20$; $t(12634) = 2.71$; $p = .006$) with similar task choice latencies for low error probabilities of the performed task and low error probabilities of the alternative task. However, for repetition trials, but not for switch trials, task choice latency decreased with increasing error probabilities of the performed task and increasing error probabilities of the alternative task⁷. The four-way interaction of *error probability of the performed task*, *error probability of the alternative task*, $error_{n-1}$, and *task transition* was significant ($b = 446.30$; $t(3753) = 3.05$; $p = .002$).

This four-way interaction was further explored with two distinct models for repetition trials and switch trials, respectively. For repetition trials, the two-way interaction of *error probability of the performed task* and *error probability of the alternative task* was significant ($b = -290.53$; $t(9134) = -2.35$; $p = .018$) with decreasing task choice latencies with increasing error probability of the performed task. This decrease was steeper in the event of high error probabilities of the alternative task than low error probabilities of the alternative task. The other interactions did not reveal a significant effect. For switch trials, the main effect of *error probability of the alternative task* was significant ($b = -472.65$; $t(81) = -4.05$; $p < .001$) with fast choices when the error probability of the alternative task was high compared to low. The interaction of $error_{n-1}$ and *error probability of the performed task* was significant ($b = -202.93$; $t(831) = -2.12$; $p = .033$) with post-error slowing on task choice latencies after low error probabilities of the performed task but post-error speeding on task choice latencies after high error probabilities of the performed task. The

⁷ We did not have any expectations on this interaction. The reduction in task choice latency on repetition trials with increasing error probabilities on both tasks may be due to the experimental paradigm with high error rates on both tasks on later trials in each block on which participants may have responded faster. Since we did not have any expectations on this interaction, and it was not significant in Experiment 1a, we do not further discuss it in the discussion section.

interaction of *error_{n-1}* and *error probability of the alternative task* was significant ($b = -277.36$; $t(494) = -2.82$; $p = .004$) with post-error slowing on task choice latencies after low error probabilities of the alternative task but post-error speeding on task choice latencies after high error probabilities of the performed task. The three-way interaction of *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* was significant ($b = 699.84$; $t(412) = 1.99$; $p = .048$). Results suggested post-error slowing on low error probabilities of the performed task and post-error speeding on high error probabilities of the performed task on low error probabilities of the alternative task. This pattern reversed on high error probabilities of the alternative task. Here, results suggested post-error speeding on low error probabilities of the performed task and post-slowing on high error probabilities of the performed task.

Discussion

Experiment 1a and 1b were composed to examine whether transient error effects, sustained error effects on the performed task and the alternative task, or both - transient and sustained error effects - influence voluntary task choices. Therefore, we composed a task environment in which the error rate of the performed task but not the alternative task increased with ongoing trials in a block. We compared the fit of five statistical models which included combinations of the three factors *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task*. Results of Experiment 1a and 1b showed that the most complex model which included all three factors predicted voluntary task choices best. The task choice results as well as task choice latencies are discussed in the following section. Participants' performance results are documented in the supplement material.

The error probability of the performed task revealed no significant effect in Experiment 1a, but results of Experiment 1b showed that high error probabilities of the performed task pushed participants away from this task to the alternative task. In addition, both experiments suggested that low error probabilities of the alternative task pulled participants' choice to switch to this alternative task. The results of these two main effects were further qualified by a significant interaction of these two factors, with increasing probabilities to switch to the alternative task with increasing error probabilities of the performed task, and low, but not high, error probabilities of the alternative task. This interaction suggests that (a) participants kept track of the error probability of both task choices and (b) participants traded-off both error probabilities with each other. These results are in line with the prediction of the EVC theory (Shenhav et al., 2013) that voluntary task choices are based on a trade-off between costs, in terms of mental effort, associated with each task option, when no rewards are provided, with the aim of choosing the task with the highest expected value – in this case the task with the least mental effort. While these results support the idea that voluntary task choices are influenced by sustained error effects, two further interactions support the idea that voluntary task choices are influenced by transient error effects. While Experiment 1a suggested a significant interaction of $error_{n-1}$ and *error probability of the performed task*, Experiment 1b revealed a significant interaction of $error_{n-1}$ and *error probability of the alternative task*. The patterns of both interactions suggest that errors, compared to correct responses, (a) increase the probability to switch tasks on high error probabilities of the performed task, compared to low error probabilities of the performed task (Experiment 1a) or (b) increase the probability to switch tasks on low error probabilities of the alternative task compared to high error probabilities of the alternative (Experiment 1b). Again, these two interactions support the prediction of the EVC theory: transient errors signal increased control demands for the next trial. The results of the two

interactions support this idea showing that participants were more likely to switch away from the performed task after errors in situations where the performed task was associated with overall high control demands (i.e., due to high error probabilities of the performed task; Experiment 1a) or in situations where the alternative task was associated with overall low control demands (i.e., due to low error probabilities of the alternative task; Experiment 1b). Finally, the predictions of the EVC theory gained more support from a three-way interaction in Experiment 1a. Results showed that participants' probability to switch to the alternative task was highest after (a) an erroneous response, (b) when the performed task was associated with a high error probability, and (c) when the alternative task was associated with a low error probability (Figure 4). However, this three-way interaction was not significant in Experiment 1b.

Experiment 1a and 1b varied in the number of signal to noise ratios applied, which may have caused the lack of replicating all results (interaction effects) of Experiment 1a with Experiment 1b. While Figure 3 shows that error rates increase with each signal to noise level in Experiment 1a, the error rates do not vary between the first three signal to noise ratio levels in Experiment 1b. This difference between the two experiments may have caused the missing replications of results. Nevertheless, results of both experiments revealed that voluntary task choices depended on transient and sustained error effects. Participants traded-off sustained error effects of both tasks against each other and transient error increased participants' choices to switch tasks in situations where current control demands were high or in situations where control demands for the alternative task were low, and in situations which combined these scenarios.

In a second step, we examined which of the five statistical models explained task choice latencies best. In line with task choices, task choice latencies were best explained by the statistical

model which included all factors⁸. Results showed that task choice latencies were slower after errors than after accurate responses on the previous trial in both experiments. This result suggests that the effect of post-error slowing, previously observed in responses after errors in single-tasking studies (Danielmeier & Ullsperger, 2011), extends to task choice latencies. In both experiments, task choice latencies were faster with increasing error probabilities of the performed task and with increasing error probabilities of the alternative task. These two main effects may hint towards longer evaluation processes of the two task choices with low error probabilities of the performed task or the alternative task. The fourth main effect revealed that participants took more time on switch trials than on repetition trials in both experiments, in line with previous results on switch costs on task choice latencies (Poljac et al., 2012), and may suggest that participants engaged in task reconfiguration processes (as suggested by previous task switching theories; e.g., Meiran, 1996) before they indicated their task choice.

The interaction of post-error slowing on task choice latencies for repetition trials, but not for switch trials, in both experiments, replicate previous findings (Smith et al., 2020) and extend these previous findings on stimulus response times to task choice latencies. However, this two-way interaction further interacted with the error probability of the performed task and the alternative task, respectively.

More precisely, both experiments suggest that post-error slowing on task choice latencies reduced with increasing error probability of the performed task or with increasing error probability of the alternative task, or both (i.e., the three-way interaction). The results of these three interactions are in line with previous observations on the orienting account (Houtman & Notebaert,

⁸ Please note that the factor *task transition* was added as an additional factor in each model, indicating whether participants selected to repeat or switch tasks.

2013; Notebaert et al., 2009) which suggested that single errors elicit an orienting response (which takes time and thus responses are slow on the following trial) in situations with low error probabilities, but not high error probabilities. While the studies by Notebaert and colleagues observed these results in single-tasking studies and for response latencies during task execution, this study extends these findings to task choice latencies and shows that this effect also depends on the error probability of the alternative task. Interestingly, these results are not fully in line with predictions made by Wessel (2017) who distinguished between two types of post-error slowing effects: orienting-related post-error slowing and strategic post-error slowing, with orienting-related post-error slowing occurring when not enough time is provided to strategically adjust to the next trial and strategic post-error slowing occurring when enough time is provided to adjust control-settings for the next trial. In both experiments, participants were provided with enough time after each stimulus response (5000ms) to select which task to choose next. If the orienting-response would only occur under circumstances when not enough time was given, participants should not have switched to the alternative task under these circumstances. The other interaction effects on task choice latencies were not consistent across both experiments and are thus not further discussed.

In sum, these results suggest that participants' voluntary task choices as well as task choice latencies are influenced by transient error effects as well as sustained error effects (for the performed task as well as the alternative task). In both experiments, participants received feedback after each trial. Thus, it is unclear whether participants switched tasks due to negative feedback or due to increases in cognitive control after an erroneous response.

Experiment 2

In Experiment 1a and 1b, participants received feedback. The results of these experiments might thus be influenced by feedback processing. Therefore, the aim of Experiment 2 was to investigate whether the results of Experiment 1a and 1b would replicate when not providing participants with response contingent feedback.

Method

Participants

Thirty-four students (25 females; $M_{age} = 22.4$; $SD_{age} = 3.1$) from the University of Freiburg, Germany performed the experiment and received 8 Euros for their participation. None of the participants were excluded and none of the students participated in Experiment 1a or Experiment 1b. The sample size was collected after the previous two experiments and was based on the G*power estimation of Experiment 1a with a minimum of 34 participants. We additionally simulated post-hoc power analyses on the significant results of this experiment. Each power analysis was based on 100 simulations. The first power simulation on the significant effect of *error_{n-1}* with an effect size (beta) of -0.28 and an alpha level of 0.05, revealed a power of 54% (95%-CI = 38-68%). A second power simulation on the significant effect of *error probability of the performed task* with an effect size (beta) of 2.07 and an alpha level of 0.05, revealed a power of 84% (95%-CI = 71-93%). A third power simulation on the significant *alternative error probability* effect with an effect size (beta) of -6.61 and an alpha level of 0.05, revealed a power of 100% (95%-CI = 92-100%). A fourth simulation on the interaction effect of *error_{n-1}* and *error probability of the performed task* with an effect size (beta) of 1.07, and alpha level of 0.05, revealed a power of 88% (95%-CI = 76-96%). A fifth simulation on the interaction effect of *error_{n-1}* and *alternative error probability* with an effect size (beta) of 1.28, and alpha level of 0.05, revealed a

power of 78% (95%-CI = 64-89%). Finally, a sixth simulation on the significant three-way interaction with an effect size (beta) of -3.85, and an alpha level of 0.05, revealed a power of 94% (95%-CI = 83-99%).

Stimulus, Procedure, and Data Analysis

The same voluntary task switching paradigm as in Experiment 1a was used with the same experimental settings, with the same number of blocks and trials. However, participants were not provided with any feedback after trial responses and a black screen appeared instead of feedback for 701ms. The same analysis procedure as in Experiment 1a and Experiment 1b was applied.

Results

As in the previous two experiments, we excluded the first trial of each block (1.00%), all trials with response times below 200ms or when participant did not respond within 1000ms (18.54%). For the RT analysis, all incorrect trials were removed (30.28%). The manipulation of decreases in the signal to noise ratio to increase error rates was successful (see Figure 3). The influence of decreases in the signal to noise ratio on RTs are depicted in S1.

Task Choices

The model comparison revealed that Model 5 fitted the data best with respect to log likelihoods, however, the BIC criterion suggested that Model 3 fitted the data slightly better than Model 5 (see Table 1). Please note that the sample size of Experiment 2 was smaller than the sample sizes of the previous two experiments and that small sample sizes are punished more using the BIC criterion for more complex models (Burnham & Anderson, 2002). As the purpose of this experiment was to replicate the results of Exp. 1a and 1b, we describe the results of Model 5 here. Moreover, we compared the fit of both models with each other with an ANOVA which suggested

no significant differences between model fits ($p = .11$). Figure 4 shows the influence of the three predictor variables on the probability to switch to the alternative task. The random effect structure comprised a random slope for each main effect and a random intercept for participants⁹. All results are listed in Table 2.

The main effect $error_{n-1}$ was significant ($b = -0.28$; $z = -2.28$; $p = .022$) with a high probability to switch after an error compared to a correct response. The main effect *error probability of the performed task* was significant ($b = 2.07$; $z = 2.97$; $p = .002$) with higher probabilities to switch to the alternative task with increasing error probability of the performed task. The main effect *error probability of the alternative task* was significant ($b = -6.61$; $z = -5.85$; $p < .001$) with lower probabilities to switch to the alternative task with increasing error probability of the alternative task. The two-way interaction of $error_{n-1}$ and *error probability of the performed task* was significant ($b = 1.07$; $z = 2.97$; $p = .002$) with a higher probability to switch to the alternative task after an error compared to a correct response but only when the error probability of the just performed task was high and a reversed effect of $error_{n-1}$ when the error probability was high. Yet, given that this reversed effect did not occur in Experiment 1a or 1b, we refrain from interpreting it. The two-way interaction of $error_{n-1}$ and *alternative error probability* was significant ($b = 1.28$; $z = 2.94$; $p = .003$) with a high probability to switch to the alternative task after an error compared to accurate responses. However, this difference decreased with increasing error probability of the alternative task. The two-way interaction of *error probability of the performed task* and *alternative error probability* was not significant ($b = 0.86$; $z = 0.68$; $p = .493$). The three-

⁹ As in Experiment 1a and Experiment 1b, we tested the robustness of the results with the two alternative random effect structure models (1 |subject_id) and ($error_{n-1} + error\ probability\ of\ the\ performed\ task + error\ probability\ of\ the\ alternative\ task$ |subject_id/block) and for the model which included the predictor *last task*. Results did not vary between these models.

way of interaction *error_{n-1}*, *error probability of the performed task*, and *alternative error probability* was significant ($b = -3.85$; $z = -3.22$; $p = .001$) with an increased probability to switch to the alternative task after an error, compared to a correct response, but only when the alternative task was associated with low error probabilities and when the just performed task was associated with high error probabilities (see Figure 4).

Task Choice Latencies

BIC suggested that Model 2 fitted the data best, while log likelihoods suggested that Model 5 fitted the data best (see Table 3). An ANOVA comparing these two models suggested that Model 5 significantly fitted the data best ($p < .001$). We thus selected Model 5 as the winning model. The influence of the three factors *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* variables on task choice latencies are depicted in Figure 4, for repetition trials, and Figure 5, for switch trials. The random effect structure comprised a random slope for *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task*, but not for *task transition* and a random intercept for participants. We report the results of all main effects and all significant interactions of this winning model in the following section. The full results of task choice latencies are described in Table 4.

The main effect of *error_{n-1}* was significant ($b = 71.49$; $t(11526) = 3.63$; $p < .001$) with 71ms slower choices after errors than accurate responses (post-error slowing). The main effect of *error probability of the performed task* was significant ($b = -230.78$; $t(1220) = -3.97$; $p < .001$) with 2ms faster task choice latencies for each percent increase in error probability of the performed task. The main effect of *alternative error probability* was significant ($b = -171.56$; $t(1024) = -2.42$; $p = .015$) with 2ms faster task choice latencies for each percent increase in alternative error probability. The main effect of *task transition* was significant ($b = 248.63$; $t(34) = 4.80$; $p < .001$), participants

took 249ms longer to decide to switch rather than to repeat a task. The two-way interaction of *error probability of the performed task* and *task transition* was significant ($b = -123.34$; $t(19059) = -2.20$; $p = .027$) with higher switch costs with increasing error probabilities of the performed task.

Discussion

The result patterns of Experiment 2 replicated the main findings of Experiment 1. Task choices depended on transient error effects and sustained error effects of the performed task and the alternative task as predicted by the EVC theory. Unlike the first two experiments, the probability to switch to the alternative task increased after errors, compared to correct responses. But please note that this main effect interacted with the error probability of the performed task and the error probability of the alternative task (see below). This interaction mimicked the results of Experiment 1 with highest switch rates after errors, on either high error probabilities of the performed task, or low error probabilities of the alternative task, or both. Together, results of Experiment 2 provided further evidence that (a) participants kept track of the error probabilities of both tasks, (b) these two tasks were traded-off against each other, and (c) that single errors increased the probability to switch tasks in situations where the trade-off favored the alternative task. Importantly, Experiment 2 indicates that errors, not error feedback, drive these effects.

As in Experiment 1, task choice latencies were best explained with Model 5. Compared to previous results, all four main effects were replicated in Experiment 2, with post-error slowing on task choice latencies, faster task choice latencies with increasing error probability of the performed and the alternative task, and increased task choice latencies on switch trials, compared to repetition trials. None of the interactions that were significant in both Experiment 1a and 1b replicated in

Experiment 2, but we observed a significant interaction of *error probability of the performed task* and *task transition* which suggested higher switch costs with increasing error probabilities of the performed task.

Experiment 3

The results of the experiments described above suggest that performance errors (error probabilities *and* errors on the previous trial) influence voluntary task choices. However, in all described experiments, error probabilities increased with time since the last switch. It may be that participants switched tasks because they got bored performing one task, or because they assumed that the experimenter expected them to switch between tasks after some trials, as this was repetitively offered after each trial. To control for these alternative interpretations of our results and to provide more support for our previous findings that performance errors influence voluntary task choices, we conducted one control experiment in which signal to noise ratios of both tasks did not change over time.

We first analyzed the probability to switch tasks as a function of trials since the last switch to ask whether participants switched tasks after some time has passed even without changing signal to noise ratios. In addition, we carried out further between-experiment analyzes to examine differences between the control Experiment 3 and the above-described experiments, respectively. In particular, we investigated the number of trials since the last switch, as well as switch rates as a function of experiments. We expected that without changes in signal to noise ratios - and thus, no expected changes in error probabilities - the number of trials since the last switch should be higher for Experiment 3, compared to the other experiments. Conversely, we expected switch rates to be significantly lower in this control experiment, compared to each of the other experiments.

Method

Participants

Fifty German participants (32 females; $M_{age} = 25.9$; $SD_{age} = 4.1$) were recruited with Prolific and received £5 (about \$7) for participation in this online experiment. The sample size was collected after the previous experiments and was based on the sample sizes of these experiments. Prior to this experiment, we defined an exclusion criterion of at least 60% accuracy which participants should meet. Based on this exclusion criteria, 13 participants were excluded before data analysis. Thus, the final sample of Experiment 3 comprised 37 participants.

Stimulus, Procedure, and Data Analysis

We applied the same voluntary task switching paradigm as in Experiment 2. However, we kept the signal to noise ratio constant. We selected a motion coherence of 18% and a color coherence of 59% as these two percentages mimicked error probabilities of around 20% in the previous experiments (see Level 3 in Experiment 1b and Experiment 2 and Level 5 in Experiment 1b). Consequently, we deleted the instruction at the beginning of the experiment that the difficulty of the selected task would increase while the difficulty of the non-selected task would stay the same. Instead of collecting data in the lab on a browser via jsPsych, we collected data online. Please note the comparability of the data quality of online experiments with experiments conducted inside the lab (Buhrmester et al., 2011; Crump et al., 2013).

We first investigated whether the number of trials since the last task switch would also significantly predict participants voluntary task choices. Therefore, we evaluated a logistic mixed regression model with a *count* variable as independent variable, indicating the number of trials since the last task switch and a *task transition* variable as depended variable. A random intercept

for each participant was added to the regression model. No random slope for *experiment* was added as this model was too complex. We expected that the number of trials since the last task switch would *not* predict participants probability to switch tasks.

As non-significant observations are difficult to interpret, we carried out two further sets of analyzes to investigate whether the number of trials since the last task switch would be less when signal to noise ratios varied, compared to when they did not vary. Therefore, we fitted three separate logistic mixed models each of which included an *experiment* predictor variable as independent variable and the *count* variable as depended variable. A random intercept for each participant was added to the regression model, but no random slope for *experiment* was added as these models were too complex. In each of these models, we compared Experiment 3 with one of the other experiments reported above. In a final set of analyzes, we conducted a similar set of three logistic mixed models each of which assessed participants probability to switch tasks as a function of *experiment*. A random intercept for each participant was added to the regression model as well as a random slope for *experiment* was added to these models¹⁰. We expected more trials since the last task switch and thus lower switch rates in Experiment 3 compared to the other experiments.

Results

With regards to the data collected in Experiment 3, and as in the previous experiments, we excluded the first trial of each block (1.00%). In addition, all trials with response times below 200ms or when participant did not respond within 1000ms (22.99%) were excluded. The error rate of this experiment was 20.6% and with that similar to the average error rate of the other experiments applying these signal to noise ratio levels.

¹⁰ Results were the same when only including a random intercept for subjects in the regression model.

Task Choices

The main effect of *count* on participants' probability to switch tasks was not significant ($b = -64.19$; $z = -0.01$; $p = .996$). However, this non-significant finding cannot be taken as evidence that participants' probability to switch tasks was not influenced by the number of trials since the last task switch. The succeeding analyses were thus conducted to provide evidence that the number of trials since the last task switch was indeed different between experiments and thus resulted in lower task switches in Experiment 3.

Between-Experiments Comparisons

The results of the below-described analyses are depicted in Figure 7. The between experiments results were clear cut: the number of trials since the last task switch were significantly higher, compared to Experiment 1a ($b = 5.54$; $t(93) = 5.50$; $p < .001$) and Experiment 2 ($b = 5.30$; $t(69) = 4.21$; $p < .001$). The comparison with Experiment 1b was not significant ($b = 0.84$; $t(81) = 0.53$; $p = .594$). Note that this result must be interpreted with caution as Experiment 1b included more trials within a block. These results were further underpinned by higher switch rates for all experiments with varying signal to noise ratios, compared to Experiment 3 (Experiment 1a vs. Experiment 3: $b = -1.08$; $z = -5.10$; $p < .001$; Experiment 1b vs. Experiment 3: $b = -0.87$; $z = -3.55$; $p < .001$; Experiment 2 vs. Experiment 3: $b = -1.00$; $z = -4.23$; $p < .001$).

Discussion

Experiment 3 was carried out to control for other explanations of why participants may have switched between tasks such as getting bored of repetitively selecting the same task or because of experimenter expectations, since this possibility is offered after every trial. Therefore, we first investigated participants' probability to switch tasks as a function of trials since the last

switch. This analysis revealed no significant effect. We additionally investigated whether the results of the control Experiment 3 varied with respect to the number of trials since a task switch and with respect to switch rates. Results suggested that the number of trials since a task switch were significantly higher for Experiment 3 compared to Experiment 1a and Experiment 2 which had the same number of trials within a block (see Figure 7). These results were accompanied by significantly higher switch rates on all three experiments with varying the signal to noise ratio of the performed task and thus varying error probabilities, compared to Experiment 3 (see Figure 7). Importantly, data of Experiment 3 were collected online. But other than the difference from collecting data on a browser on a computer inside the lab, compared to on a browser on a computer online, and without varying signal to noise ratio and a minor instruction change, the experimental setup was exactly the same. Together, these results support the previous results that performance errors influence voluntary task choices.

General Discussion

The present study investigated whether and how errors influence voluntary task choices in situations with multiple tasks available. Based on previous theories on error processing and results from voluntary task selection studies, we derived distinct statistical models to predict how transient and/or sustained error effects influence task choices. We compared the fit of these models on data from a new voluntary task switching paradigm in which participants could freely choose between two perceptual discrimination tasks. In this paradigm, the signal to noise ratio of the performed task decreased with task repetitions while the signal to noise ratio of the alternative (not performed) task remained on the same signal to noise ratio level. This manipulation led to increases in error probability for the performed task, respectively. Model comparison suggested that transient errors

as well as sustained errors influence voluntary task choices. More precisely, the winning model included (a) whether the previous response was incorrect or correct, (b) the error probability of the performed task, and (c) the error probability of the alternative task. Results of this winning model suggested that participants were most likely to switch tasks after an error in the previous trial when (a) the error probability of the performed task was high (Experiment 1a and Experiment 2), (b) the error probability of the alternative task was low (Experiment 1b and Experiment 2), or (c) both, high error probabilities of the performed task and low error probabilities of the alternative task (Experiment 1a and Experiment 2). Importantly, transient and sustained error effects were found both with error feedback (Experiment 1a and 1b) and without error feedback (Experiment 2), which makes it unlikely that the present findings can be attributed to feedback processing, but rather suggests an internal monitoring process of errors that influences task choices. In the remainder of the discussion, we relate these results to previous work and review different perspectives on error processing that can account for the current results.

Errors Impact on Task Selection

In this research project, we asked how theoretical accounts, initially developed to explain error processing in single-tasking, can explain voluntary selection when exposed to multiple tasks. Therefore, we derived predictions from research on voluntary task switching (Orr et al., 2012) on transient error effects (Model 1), from demand avoidance studies (Kool et al., 2010) on sustained error effects (Model 2 and Model 3), from studies on maladaptive accounts on error processing (Jentsch & Dudschig, 2009; Notebaert et al., 2009; Wessel, 2018; Wessel & Aron, 2017) with a particular focus on the interaction between transient error effects and sustained error effects of the performed task (Model 4), and finally from the EVC theory (Shenhav et al., 2013) which integrates

transient error effects and sustained error effects of the performed task and alternative task (Model 5).

Results of the current study show that transient error effects led to increased task switch rates. This finding is at odds with previous reports suggesting that transient error effects decrease switch rates (Orr et al., 2012). We conjecture that these contrasting results can be attributed to the stimulus material employed. Orr and colleagues used bivalent stimuli that are associated with both tasks, while we used univalent stimuli that can be processed only for one task. Bivalent stimuli result in between-task interference and thus require that the currently relevant task is activated more strongly while the alternative task is de-activated (some accounts would even assume inhibited, see e.g. Kiesel, et.al. (2010), for a discussion). This makes the alternative task less available during task selection and overshadows the switch bias observed in the current study with univalent stimuli (see Dignath et al., 2015 for a detailed discussion).

In addition to transient error effects, results are in line with previous studies showing that sustained error effects influence task choices in favor of tasks and contexts associated with relatively lower probabilities to commit an error (Kool et al., 2010; Wisniewski et al., 2015). More precisely, participants seemed to keep track of the cognitive demand associated with both task options with highest switch rates on either high error probabilities of the performed task or low error probabilities of the alternative task. Moreover, both factors interacted with each other (in Experiment 1a and 1b) with highest switch rates on high error probabilities of the performed task and low error probabilities of the alternative task. These results suggest that a complete account of sustained error effects has to incorporate error histories of both tasks and that participants seemed to trade-off these error histories against each other (see below for a more detailed discussion on this).

With regards to the interplay of transient error effects and sustained error effects of the performed task, results of Experiment 1a and Experiment 2 suggested increased switch rates after errors, compared to correct responses, with increasing error probabilities of the performed task. These task selection results stand in contrast with predictions derived from Notebaert et al. (2009) suggesting an orienting response after errors in conditions with *low* error probabilities (and not *high* error probabilities) which biases attention away from the current task and presumably leads to increased switch rates (also see Wessel, 2018). Yet, the result patterns of task choice latencies (and RTs) are in line with results on the orienting account on error processing (Houtman & Notebaert, 2013; Notebaert et al., 2009), with decreased post-error slowing on increasing error probabilities of the performed task. The opposing result pattern of increased post-error slowing on *low* error probabilities of the performed task but increased post-error switching on *high* error probabilities of the performed task may suggest two (or more) distinct mechanisms in play that influence task choice latencies and task selection decisions. To the best of our knowledge, this study provides first evidence of these distinct result patterns of task choice latencies and task selections and provide an interesting avenue for future studies on the influence of performance adjustments on task selection processes.

Going beyond previous work, the present results highlight the interplay between transient and sustained error effects of the performed task and the alternative task. In Experiment 1a and Experiment 2, the three-way interactions of *error_{n-1}*, *error probability of the performed task*, and *error probability of the alternative task* were significant with an increased probability to switch tasks after an error, compared to a correct response, if the error probability of the performed task was high and the error probability of the alternative task was low. These results suggest that an error on the previous trials weighs on top of the general error probability for the task selection

process and that the impact of the recent error on the decision to switch depends on the error probability of the performed and the alternative task. We are aware that this idea is not new. In fact, already the conflict monitoring model used a learning parameter to discount the strength of control signals over time (Botvinick et al., 2001). Yet, to the best of our knowledge, the present research is the first to provide direct evidence that transient as well as sustained error effects impact voluntary task selection.

These results are in line with predictions made by the EVC theory (Musslick et al., 2015; Shenhav et al., 2013). According to this theory, humans trade-off costs and benefits associated with each task option with each other, to select the task with the highest expected value. In the present experiments, monetary rewards were not provided, but costs varied with the amount of control required. Thus, the decision to switch was driven by the trade-off between anticipated control demands to successfully respond to each task (reflecting sustained error effects), in addition to the anticipated need to increase control demands (accompanied with increased costs) on the performed task after an erroneous response (reflecting transient error effects). The present results regarding task choices are compatible with this idea by showing that transient and sustained error effects influence subsequent task choices. Interestingly, the current result pattern revealed increased task choice latencies after errors compared to correct responses even on switch trials. This result hints towards increased control allocation even for the task participants switched to (i.e., the non-performed task in $n-1$) which does not speak in favor of a task specific control allocation process after errors but rather favors general increase in control after error commission, eventually caused by a general negative affective response after errors (see below). However, this study was not conducted to investigate whether single errors induce a general control allocation

process or a task specific process. Thus, further studies are needed to investigate this research question.

We want to point out that the present results may also be interpreted with theories from research on affective decision making. They suggest that decision makers compare the value of different options and base their choice on the reinforcement history of events (see Roberts & Hutcherson, 2019 for a review). Interestingly, errors in simple cognitive tasks also trigger affective responses. Using facial Electromyography as an implicit measure of valence, Dignath and colleagues (2019) showed that errors (with and without feedback) elicited a quick negative affective reaction in the first 100ms after incorrect responding. Interestingly, this affective response has been linked to the strength of post-error slowing (see also Lindström et al., 2013). Furthermore, previous research showed that stimuli with a history of many errors led to a stronger motivational tendency to avoid the stimulus (Dignath & Eder, 2015; Schouppe et al., 2012). According to this perspective, choice biases due to transient and sustained error effects could result from affective evaluation of errors and motivational responses to errors. We should also note that this affective view and the control perspective described above are not mutually exclusive. Indeed, it has been suggested that changes in control are caused by affective response to errors (Dignath et al., 2020; Inzlicht et al., 2015; van Steenbergen, 2015).

In line with task choices, task choice latencies were best explained with Model 5 which included transient and sustained error effects of the performed and alternative task. Results of this model replicated previous observations of switch costs on task choice latencies (Poljac et al., 2012) and suggest task set reconfiguration processes during the task selection process (Monsell, 2003; Monsell et al., 2003; Rogers & Monsell, 1995). In addition, we replicated previous results on the interaction of the effects on transient errors and post-error slowing (highlighted above), and

extended these effects to task choice latencies but also RTs (see supplementary material for results on RTs; Houtman & Notebaert, 2013; Notebaert et al., 2009).

Based on a reviewers' comment, we would also like to note that the observed effects may result from perceptual representations of uncertainty which then cause errors in our experiments. Following this notion, one may argue that each perceptual representation comprises an uncertainty representation (Knill & Richards, 1996; Pouget et al., 2013). This idea is further supported by a recent study showing that the perceptual quality of the stimulus affected judgments on confidence in perceptual decisions (Rausch et al., 2018). Even though voluntary task choices may differ from confidence judgments, both involve a similar aspect of metacognition, and thus voluntary task choices might not be based on error probability, but on the percept of the coherence of the RDK during the motion discrimination task or the percept of color dominance during the color discrimination task. We acknowledge that with the current paradigm, we cannot rule out whether the reported effects are based on error probabilities or perceptual confidence. Future research may disentangle the effect of perceptual representations of uncertainty and/or error probabilities on voluntary task choice.

Summary

Single-tasking studies addressed the questions on how errors influence our behavior in terms of performance shifts within the same task (Botvinick et al., 2001; Brown & Braver, 2005; Laming, 1968; Notebaert et al., 2009; Rabbitt & Rodgers, 1977; Yeung, 2004; Yeung et al., 2004). During the past decade, the question arose on how errors may influence our behavior not only in terms of performance adjustments on the subsequent trial on the same task but also when facing the decision which of two (or more) tasks to engage with next (Alexander & Brown, 2011; Shenhav et al., 2013; Vassena et al., 2019, 2020). In this course, the EVC theory suggested that not only the

performed task but all available task options are traded-off against each other in such situations. The present results support this prediction. In sum, this research project shows that task choices are driven by the interplay of transient (error in $n-1$) and sustained (error probability of performed and alternative task) error effects. These present results inform decision making theories to consider other factors than rewards in human decision making.

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Figures and Tables

Table 1

Five Distinct Statistical Models With Task Choice as the Dependent Variable. Combinations of the Three Possible Predictor Variables, Error_{n-1}, Error probability of the Performed Task (EL_{performed task}), and Error probability of the Alternative Task (EL_{alternative task}), Including Their Interactions, are Listed in the Formula Column. The Degrees of Freedom (df) are Listed for Each Model as Well as the BIC and Log Likelihoods (LL).

Model	Formula	Experiment 1a			Experiment 1b			Experiment 2		
		Task choice			Task choice			Task choice		
		df	BIC	LL	df	BIC	LL	df	BIC	LL
Model 1	Error _{n-1}	5	17298.04	-8622.8	5	14591.88	-7269.5	5	11092.70	-5521.4
Model 2	EL _{performed task}	5	17657.53	-8802.5	5	15157.40	-7552.3	5	11054.41	-5502.2
Model 3	EL _{performed task} × EL _{alternative task}	10	16543.05	-8219.1	10	14235.44	-7065.0	10	10647.31 ^a	-5273.7
Model 4	Error _{n-1} × EL _{performed task}	10	17225.98	-8560.5	10	14571.88	-7233.2	10	11101.73	-5500.9
Model 5	Error _{n-1} × EL _{performed task} × EL _{alternative task}	18	16169.91 ^a	-7990.6 ^b	18	13670.05 ^a	-6740.1 ^b	18	10714.13	-5267.2 ^b

Note. Smaller BIC and Log likelihoods closer to zero indicate better model fits.

^a Indicates the best fit to the data with respect to BIC.

^b Indicates the best fit to the data with respect to Log Likelihoods.

× Indicates the inclusion of the main effect as well as the interaction effect of the variables.

Table 2

Five Distinct Statistical Models With Task Choice Latency as the Dependent Variable. Combinations of the Four Possible Predictor Variables, Error_{n-1}, Error probability of the Performed Task (EL_{performed task}) and Error probability of the Alternative Task (EL_{alternative task}), as Well as Task Transition, Including Their Interactions are Listed in the Formula Column. The Degrees of Freedom (df) are Listed for Each Model as Well as the BIC and Log Likelihoods (LL).

Model	Formula	Experiment 1a			Experiment 1b			Experiment 2		
		Task choice latency			Task choice latency			Task choice latency		
		df	BIC	LL	df	BIC	LL	df	BIC	LL
Model 1	Error _{n-1} × Task Transition	11	517242.5	-258563.6	11	546400.5	-273142.3	11	312228.1	-156059.2
Model 2	EL _{performed task} × Task Transition	11	517246.0	-258565.4	11	546337.7	-273110.9	11	312224.8 ^a	-156057.5
Model 3	EL _{performed task} × EL _{alternative task} × Task Transition	19	517104.6	-258452.7	19	546280.7 ^a	-273040.2	19	312276.3	-156043.4
Model 4	Error _{n-1} × EL _{performed task} × Task Transition	19	517203.0	-258502.0	19	546342.5	-273071.2	19	312274.9	-156042.6
Model 5	Error _{n-1} × EL _{performed task} × EL _{alternative task} × Task Transition	32	517100.0 ^a	-258382.3 ^b	32	546313.6	-272988.2 ^b	32	312350.2	-156020.1 ^b

Note. Smaller BIC and Log likelihoods closer to zero indicate better model fits.

^a Indicates the best fit to the data with respect to BIC.

^b Indicates the best fit to the data with respect to Log Likelihoods.

× Indicates the inclusion of the main effect as well as the interaction effect of the variables.

Table 3

Estimate (*b*), Standard Error (*SE*), *z*-Value, and *p*-Value for Each Fixed Effect (Intercept, $Error_{n-1}$, Error probability of the Performed Task [$EL_{performed\ task}$] and Error probability of the Alternative Task [$EL_{alternative\ task}$]) Including Their Interactions on Task Choices of Model 5 for Each Experiment, Respectively.

Fixed effects	Experiment 1a				Experiment 1b				Experiment 2			
	<i>b</i>	<i>SE</i>	<i>z</i> -value	<i>p</i> -value	<i>b</i>	<i>SE</i>	<i>z</i> -value	<i>p</i> -value	<i>b</i>	<i>SE</i>	<i>z</i> -value	<i>p</i> -value
<i>Intercept</i>	-1.06	0.23	-4.63	< .001	-1.85	0.25	-7.37	< .001	-1.50	0.22	-6.80	< .001
$Error_{n-1}$	0.11	0.14	0.75	.447	0.23	0.15	1.52	.126	-0.28	0.12	-2.28	.022
$EL_{performed\ task}$	0.21	0.49	0.43	.661	1.66	0.53	3.09	.001	2.07	0.69	2.97	.002
$EL_{alternative\ task}$	-6.88	0.72	-9.51	< .001	-8.46	1.04	-8.10	< .001	-6.61	1.13	-5.85	< .001
$Error_{n-1} \times EL_{performed\ task}$	0.71	0.34	2.10	.035	-0.25	0.36	-0.70	.483	1.07	0.36	2.97	.002
$Error_{n-1} \times EL_{alternative\ task}$	0.66	0.38	1.72	.085	0.85	0.42	1.99	.045	1.28	0.43	2.94	.003
$EL_{performed\ task} \times EL_{alternative\ task}$	3.85	1.13	3.40	< .001	6.12	1.45	4.27	< .001	0.86	1.26	0.68	.493
$Error_{n-1} \times EL_{performed\ task} \times EL_{alternative\ task}$	-2.04	1.03	-1.98	.047	0.32	1.37	0.24	.810	-3.85	1.19	-3.22	.001

Note. $\times$ Indicates the interaction of two variables.

Table 4

Estimate (*b*), Standard Error (*SE*), *t*-Value, and *p*-Value for Each Fixed Effect (Intercept, $Error_{n-1}$, Error probability of the Performed Task [$EL_{\text{performed task}}$], Error probability of the Alternative Task [$EL_{\text{alternative task}}$], and Task Transition [TT]) Including Their Interactions on Task Choice Latencies of Model 5 for Each Experiment, Respectively.

Fixed effects	Experiment 1a				Experiment 1b				Experiment 2			
	<i>b</i>	<i>SE</i>	<i>t</i> -value	<i>p</i> -value	<i>b</i>	<i>SE</i>	<i>t</i> -value	<i>p</i> -value	<i>b</i>	<i>SE</i>	<i>t</i> -value	<i>p</i> -value
Intercept	731.39	43.20	16.93	< .001	681.57	54.60	12.48	< .001	661.33	59.73	11.07	< .001
$Error_{n-1}$	121.91	18.34	6.64	< .001	59.93	12.62	4.74	< .001	71.49	19.68	3.63	< .001
$EL_{\text{performed task}}$	-265.42	55.06	-4.82	< .001	-159.10	50.39	-3.15	.001	-230.78	58.04	-3.97	< .001
$EL_{\text{alternative task}}$	-339.77	71.61	-4.74	< .001	-166.86	55.41	-3.01	.002	-171.56	70.77	-2.42	.015
TT	225.53	34.22	6.59	< .001	278.71	50.06	5.56	< .001	248.63	51.79	4.80	< .001
$Error_{n-1} \times EL_{\text{performed task}}$	-294.79	50.55	-5.83	< .001	-149.48	40.12	-3.72	< .001	-66.37	55.11	-1.20	.228
$Error_{n-1} \times EL_{\text{alternative task}}$	-164.54	57.17	-2.85	.004	-172.96	42.13	-4.10	< .001	-86.84	66.13	-1.31	.189
$Error_{n-1} \times TT$	59.17	18.05	3.27	.001	42.72	12.01	3.55	< .001	29.99	19.59	1.53	.125
$EL_{\text{performed task}} \times EL_{\text{alternative task}}$	342.27	165.11	2.07	.038	124.05	160.36	0.77	.439	217.81	185.79	1.17	.241
$EL_{\text{performed task}} \times TT$	37.73	52.17	0.72	.469	-136.62	44.31	-3.08	.002	-123.34	55.84	-2.20	.027
$EL_{\text{alternative task}} \times TT$	-53.65	59.40	-0.95	.366	-111.76	49.88	-2.24	.025	-18.67	66.98	-0.27	.780
$Error_{n-1} \times EL_{\text{performed task}} \times EL_{\text{alternative task}}$	517.18	155.43	3.32	< .001	432.39	147.26	2.93	.003	-144.69	178.92	-0.80	.418
$Error_{n-1} \times EL_{\text{alternative task}} \times TT$	-42.83	57.60	-0.74	.457	-167.78	41.84	-4.01	< .001	-40.87	66.06	-0.61	.536
$Error_{n-1} \times EL_{\text{performed task}} \times TT$	-147.01	50.34	-2.92	.003	-125.83	39.76	-3.16	.001	7.76	55.01	0.14	.887
$EL_{\text{performed task}} \times EL_{\text{alternative task}} \times TT$	-155.06	161.82	-0.95	.337	432.20	159.40	2.71	.006	-4.88	183.63	-0.02	.978
$Error_{n-1} \times EL_{\text{performed task}} \times EL_{\text{alternative task}} \times TT$	190.33	154.59	1.23	.218	446.30	145.88	3.05	.002	-201.99	178.62	-1.13	.258

Note. $\times$ Indicates the interaction of two variables.

Fig 1. Example of a possible task choice sequence and the related decrease of signal to noise ratio. Participants selected between a color discrimination task (indicated by red lines) and a motion discrimination task (indicated by black lines). In the example, the motion discrimination task was selected consecutive times with decreasing signal to noise ratios every 6-9 trials until the color discrimination task was selected (event marked with the arrow). This task was then selected consecutive times accompanied with signal to noise ratio decreases until the participant switched to the motion discrimination task. The signal to noise ratio of the motion discrimination task remained on the same level until it was selected again. With this setup, the error probability of the selected task increased throughout the block run, while the error probability of the alternative task stayed at the same level until it was selected. At the beginning of each block, the signal to noise ratio of both tasks was reset to the initial signal to noise ratio levels.

Fig 2. Example trial sequence. Participants had to select the motion or the color task before each trial, followed by a fixation cross and the selected task stimulus (motion in this example). For the motion discrimination task, participants had to detect whether the majority of the dots were moving in upward direction or in downward direction. For the color discrimination task, participants had to detect whether the majority of the dots were colored in blue or red. After a response, participants were provided with feedback (Experiment 1a & Experiment 1b) or a blank screen (Experiment 2).

Fig 3. Error rate as a function of signal to noise ratio level. We refer to the different signal to noise ratio levels as levels 1 to 6 (or 8 for Experiment 1b) with higher numbers indicating more difficult levels, that is, smaller signal to noise ratios. With increasing level, the error rate increased. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Left panel plots the error rate of the color task. Right panel plots the error rate of the motion task. Red dots indicate the average error rate. Black dots indicate the error rate of each individual for each level, respectively.

Fig 4. Probability to switch to the alternative task as a function of error_{n-1} , error probability of the performed task, and error probability of the alternative task in each experiment. The probability to switch to the alternative task increased after errors compared to accurate responses, in particular with increasing error probabilities of the performed task (depicted on the x-axis) and on low error probabilities of the alternative task (indicated as panels). Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard error.

Fig 5. Task choice latency as a function of error_{n-1}, error probability of the performed task, and error probability of the alternative task, for repetition trials and each experiment. On low error probabilities of the performed and alternative task, task choice latencies were higher after errors than correct responses. This post-error increase effect in task choice latencies decreased with increasing error probabilities of the performed task and with increasing error probabilities of the alternative task on repetition trials. Each panel within a row illustrates the model fit of a specific alternative error probability labeled on top of each panel. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard error.

Fig 6. Task choice latency as a function of error_{n-1}, error probability of the performed task, error probability of the alternative task, for switch trials and each experiment. On low error probabilities of the performed and alternative task, task choice latencies were higher after errors than correct responses. This post-error increase effect in task choice latencies decreased with increasing error probabilities of the performed task and with increasing error probabilities of the alternative task on switch trials. Each panel within a row illustrates the model fit of a specific alternative error probability labeled on top of each panel. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard errors.

Fig 7. Trials since switch (upper panels) and switch rates (lower panels) as a function of experiment. The number of trials since the last switch was higher in Experiment 3 compared to Experiment 1a and Experiment 2. Participants switched significantly more often on each of the three experiments with varying signal to noise ratios, compared to Experiment 3. Dots indicate logistic regression means for each Experiment respectively. Error bars indicate the standard error of the mean.

Supplement Material

Experiment 1a

Reaction Time

In this and the following analysis (with error rate as the dependent measure), we examined how the independent variables of Model 5 influenced the performance on stimulus responses in n. In contrast to the analyses of task choices, both independent variables regarding error likelihood were now coded in trial n. RT results are depicted in S2 and S3, respectively. All results are listed in a table in S6. Main effects and all significant interactions are described below.

The main effect of $error_{n-1}$ was significant ($b = 24.82$; $t = 3.36$; $p < .001$) with slow response times after errors compared to accurate responses. The main effect of *error likelihood of the performed task* was not significant ($b = -1.06$; $t = -0.03$; $p = .975$). The main effect of *error likelihood of the alternative task* was significant ($b = -68.07$; $t = -2.57$; $p = .010$) with faster responses when the alternative task was associated with a larger error likelihood. The main effect of *task transition* was significant ($b = 33.47$; $t = 4.10$; $p < .001$) with slow responses after a task switch compared to task repetitions. The two-way interaction of $error_{n-1}$ and *error likelihood of the performed task* was significant ($b = -78.17$; $t = -2.96$; $p = .003$) indicating post-error slowing on low but not high error likelihoods of the performed task.

Accuracy

Accuracy results are depicted in S4 and S5, respectively. All accuracy results are listed in a table in S7. We report main effects and all significant interactions below.

The main effect of $error_{n-1}$ was significant ($b = -0.25$; $z = -1.99$; $p = .046$) with decreased accuracies after an error compared to a correct response on the previous trial. The main effect of *error likelihood of the performed task* was significant ($b = -4.47$; $z = -11.64$; $p < .001$) with a lower

accuracy when the error likelihood was high. The main effect of *error likelihood of the alternative task* was not significant ($b = -0.07$; $z = -0.21$; $p = .833$). The three-way interaction of *error_{n-1}*, *error likelihood of the performed task*, and *task transition* was significant ($b = -0.82$; $z = -2.15$; $p = .031$) with post-error decreases in accuracy on repetition trials with low error likelihoods of the performed task and post-error increases in accuracy on repetition trials with high error likelihood of the performed task. On switch trials, results revealed post-error decreases in accuracy and this effect was enhanced with increasing error likelihoods of the performed task.

Experiment 1b

Reaction Time

RT results are depicted in S2 and S3, respectively. All results are listed in a table in S6. Main effects and significant interactions are described here.

The main effect of *error_{n-1}* was significant ($b = 18.39$; $t = 4.23$; $p < .001$) with slow responses after errors compared to accurate responses. In contrast to Experiment 1a, the main effect of *error likelihood for the performed task* was significant ($b = 136.52$; $t = 4.72$; $p < .001$) with slower RTs with increasing error likelihood. The main effect of *error likelihood of the alternative task* was not significant ($b = -12.45$; $t = -0.51$; $p = .606$). The main effect of *task transition* was significant ($b = 35.89$; $t = 6.66$; $p < .001$) with slow responses on switch trials compared to repetition trials. The two-way interaction of *error_{n-1}* and *error likelihood of the performed task* was significant ($b = -55.22$; $t = -3.31$; $p < .001$) with post-error slowing only for low error likelihoods of the performed task. The two-way interaction of *error likelihood of the performed task* and *task transition* was significant ($b = -53.13$; $t = -2.60$; $p = .009$) with prolonged RTs on switch compared to repetition trials but only when the error likelihood of the performed task was low. The three-

way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *error likelihood of the alternative task* was significant ($b = -95.29$; $t = 1.70$; $p = .008$) with a reduced post-error slowing effect with increasing error likelihood of the performed task on low alternative error likelihoods. On high alternative error likelihoods, the post-error slowing effect was larger on low error likelihoods of the performed task and decreased with increasing error likelihoods of the performed task and increasing error likelihoods of the alternative task. The three-way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *task transition* was significant ($b = -39.16$; $t = -2.34$; $p = .018$) with post-error slowing on repetition trials on smaller error likelihoods of the performed task but not higher error likelihoods of the performed task and no post-error slowing on switch trials, independent of the error likelihood of the performed task. The three-way interaction of $error_{n-1}$, *alternative error likelihood*, and *task transition* was significant ($b = -37.68$; $t = -2.65$; $p = .008$) with post-error slowing on repetition trials and overall faster responses with increasing error likelihood of the alternative task. On switch trials, post-error slowing decreased, and overall responses slowed down with increasing error likelihood of the alternative task. The four-way interaction was significant ($b = 211.36$; $t = 3.78$; $p < .001$).

The four-way interaction was further investigated with two distinct models for repetition trials and switch trials, respectively. The analysis for repetition trials only revealed a significant main effect of $error_{n-1}$ ($b = 17.21$; $t = 3.82$; $p < .001$) with slow RTs after errors compared to accurate responses. The main effect of *error likelihood of the performed task* was significant ($b = 192.49$; $t = 6.79$; $p < .001$) with longer RTs on trials associated with higher error likelihoods. The three-way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *error likelihood of the alternative task* was significant ($b = 116.15$; $t = -2.50$; $p = .012$) with a decreased post-error slowing effect with increasing error likelihood of the performed on low alternative error

likelihoods. On high alternative error likelihoods, the post-error slowing effect was larger on low error likelihoods of the performed task and decreased with increasing error likelihoods of the performed task and increasing error likelihoods of the alternative task. The same model, but for switch trials, revealed that the main effect on $error_{n-1}$ was significant ($b = 20.26$; $t = 2.59$; $p = .009$) with slow responses after errors compared to accurate responses. The main effect of *error likelihood of the performed task* was significant ($b = 95.69$; $t = 2.03$; $p = .044$) with slower responses with increasing error likelihoods. The interaction of $error_{n-1}$ and *error likelihood of the performed task* was significant ($b = -95.37$; $t = -3.16$; $p = .001$) with post-error-slowness on lower error likelihoods of the performed task but post-error speeding on higher error likelihoods of the performed task. The interaction of $error_{n-1}$ and *alternative error likelihood* was significant ($b = -59.99$; $t = -2.30$; $p = .021$) with post-error slowing on low alternative error likelihoods but not on high alternative error likelihoods. The three-way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *alternative error likelihood* was significant ($b = 315.31$; $t = 2.96$; $p = .003$) with post-error slowing if the error likelihoods for both tasks were either low or high and post-error speeding if error likelihoods were low/high or high/low for the performed and alternative task respectively.

Accuracy

Accuracy results are depicted in S4 and S5, respectively. All accuracy results are listed in a table in S7. Main effects and significant interactions are listed in the following section.

The main effect of $error_{n-1}$ was significant ($b = -0.22$; $z = -2.24$; $p = .024$) with less accurate responses after errors compared to correct trials. The main effect of *error likelihood of the performed task* was significant ($b = -5.38$; $z = -18.70$; $p < .001$) with lower accuracy when the error likelihood of the performed task increased. The main effect of *alternative error likelihood* was

significant ($b = -1.08$; $z = -3.47$; $p < .001$) with lower accuracy scores when the error likelihood of the alternative task increased. The main effect of *task transition* was significant ($b = -0.26$; $z = -2.67$; $p = .007$) with decreased accuracies on switch trials compared to repetition trials. The two-way interaction of *error_{n-1}* and *task transition* was significant ($b = 0.34$; $z = 3.49$; $p < .001$) with increased post-error decreases in accuracy on repetition trials compared to switch trials. The two-way interaction of *error likelihood of the performed task* and *alternative error likelihood* was significant ($b = 3.11$; $z = 3.40$; $p < .001$) with increased accuracies when the error likelihood of the performed task was low, compared to high error likelihoods of the alternative task, and decreased accuracies when the error likelihood of the performed task was high. The two-way interaction of *error likelihood of the performed task* and *task transition* was significant ($b = 0.96$; $z = 3.35$; $p < .001$) with steeper decreases in accuracy with increasing error likelihood of the performed task for repetition trials than switch trials (indicating increased switch costs on low vs. high error likelihoods of the performed task). The two-way interaction of *alternative error likelihood* and *task transition* was significant ($b = -1.01$; $z = -3.48$; $p < .001$) with overall high accuracies independent of error likelihoods of the alternative task on repetition trials, but steep decreases in accuracy with increasing error likelihoods of the alternative task on repetition trials (indicating higher switch costs with increasing error likelihoods of the alternative task). The three-way interaction of *error_{n-1}*, *error likelihood of the performed task*, and *task transition* was significant ($b = -1.18$; $z = -4.11$; $p < .001$) with post-error decreases in accuracy on low but not high error likelihoods of the performed task on repetition trials and a smaller post-error effect which was not influenced by the error likelihoods of the performed task on switch trials. The three-way interaction of *error_{n-1}*, *alternative error likelihood*, and *task transition* was significant ($b = -0.63$; $z = -2.19$; $p = .028$). On repetition trials the post-error decrease in accuracy effect decreased with increasing

error likelihoods of the alternative task. On switch trials there was no post-error decrease in accuracy effect and overall decreased in accuracy with increasing error likelihoods of the alternative task. The three-way interaction of *error likelihood of the performed task*, *alternative error likelihood*, and *task transition* was significant ($b = 1.97$; $z = 2.15$; $p = .031$). On repetition trials, the accuracy decreased steeper with increasing error likelihoods of the performed task and low, compared to high error likelihoods of the alternative task. This effect reversed on switch trials, i.e., the accuracy decreased steeper with increasing error likelihoods of the performed task and high, compared to low error likelihoods of the alternative task. The four-way interaction was significant ($b = 2.85$; $z = 3.12$; $p = .001$).

The four-way interaction was further explored with two separate analyses for repetition trials and switch trials, respectively. For repetition trials, the main effect of $error_{n-1}$ was significant ($b = -0.56$; $z = -5.60$; $p < .001$) with low accuracy after errors compared to accurate responses. The main effect of *error likelihood of the performed task* was significant ($b = -6.34$; $z = -20.84$; $p < .001$) with lower accuracy on high error likelihoods. The interaction of $error_{n-1}$ and *error likelihood of the performed task* was significant ($b = 1.61$; $z = 5.29$; $p < .001$) with post-error decreases in accuracy on low error likelihoods but not on high error likelihoods. The three-way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *alternative error likelihood* was significant ($b = -1.89$; $z = -2.19$; $p = .027$) with post-error decreases in accuracy on low error likelihoods but not on high error likelihoods. This effect was larger on low alternative error likelihoods than on high alternative error likelihoods. With regards to switch trials, the main effect of *error likelihood of the performed task* was significant with lower accuracy on high error likelihoods ($b = -3.45$; $z = -6.13$; $p < .001$). The main effect of *alternative error likelihood* was significant with lower accuracy

for increasing alternative error likelihoods ($b = -1.28$; $z = 2.35$; $p = .018$). The interactions were not significant.

Experiment 2

Reaction Times

RT results are depicted in S2 and S3, respectively. All results are listed in a table in S6. Main effects and significant interactions are described below.

The main effect of *error_{n-1}* was not significant ($b = 14.61$; $t = 1.89$; $p = .057$). The main effect of *error likelihood of the performed task* was significant ($b = 84.14$; $t = 2.14$; $p = .032$) with longer RTs for increasing error likelihoods. The main effect of *error likelihood of the alternative task* was not significant ($b = -34.69$; $t = -1.17$; $p = .244$). The main effect of *task transition* was significant ($b = 17.78$; $t = 2.01$; $p = .045$) with longer RTs on switch trials compared to repetition trials.

Accuracy

Accuracy results are depicted in S4 and S5, respectively. All accuracy results are listed in a table in S7. Main effects and significant interactions are described below.

The main effect of *error_{n-1}* was not significant ($b = 0.03$; $z = 0.17$; $p = .862$). The main effect of *error likelihood of the performed task* was significant ($b = -5.86$; $z = -10.45$; $p < .001$) with a lower accuracy when the error likelihood of the performed task was high. The main effect of *error likelihood of the alternative task* was not significant ($b = -0.62$; $z = -1.19$; $p = .233$). The two-way interaction of *error_{n-1}* and *task transition* was significant ($b = 0.54$; $z = 2.70$; $p = .006$) with post-error decrease in accuracy on repetition trials but post-error increase in accuracy on switch trials. The two-way interaction of *error likelihood of the alternative task* and *task transition*

was significant ($b = -1.19$; $z = 2.70$; $p = .021$) with increasing error likelihoods of the alternative task switch costs increased. The three-way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *task transition* was significant ($b = -1.47$; $z = -2.63$; $p = .008$) with post-error decrease in accuracy on low error likelihoods of the just performed task on repetition trials. This effect decreased with higher error likelihoods of the just performed task, but post-error increases in accuracy on switch trials and low error likelihoods of the just performed task and this effect decreasing on high error likelihoods of the just performed task. The three-way interaction of $error_{n-1}$, *error likelihood of the alternative task*, and *task transition* was significant ($b = -1.17$; $z = -2.25$; $p = .023$) with post error decreases in accuracy on repetition trials when the error likelihood of the alternative task was low, but not when it was high. For switch trials this effect was absent. The three-way interaction of *error likelihood of the performed task*, *alternative error likelihood*, and *task transition* was significant ($b = 3.67$; $z = 2.53$; $p = .011$). On repetition trials, the accuracy decreased steeper with increasing error likelihoods of the performed task and low, compared to high error likelihoods of the alternative task. This effect reversed on switch trials, i.e., the accuracy decreased steeper with increasing error likelihoods of the performed task and high, compared to low error likelihoods of the alternative task. The four-way interaction was significant ($b = 3.52$; $z = 2.42$; $p = .015$). This four-way interaction was further explored with two distinct models for repetition trials and switch trials, respectively.

For repetition trials, the main effect of $error_{n-1}$ was significant ($b = -.50$; $z = -3.84$; $p < .001$) with a low accuracy after an error on the previous trial as compared to a correct response on the previous trial. The main effect of *error likelihood of the performed task* was significant ($b = -5.24$; $z = -15.43$; $p < .001$) with lower accuracy on higher error likelihoods. The interaction of $error_{n-1}$ and *error likelihood of the performed task* was significant ($b = .92$; $z = 2.72$; $p = .006$) with post-

error decreases in accuracy on low error likelihoods but not on high error likelihoods. The interaction of $error_{n-1}$ and *error likelihood of the alternative task* was significant ($b = 1.04$; $z = 2.89$; $p = .003$) with post-error decreases in accuracy on low alternative error likelihoods but not on high alternative error likelihoods. The three-way interaction of $error_{n-1}$, *error likelihood of the performed task*, and *error likelihood of the alternative task* was significant ($b = 2.06$; $z = 2.31$; $p = .020$) with post-error decreases in accuracy on low error likelihoods but not on high error likelihoods but only when the alternative error likelihood was low and not when it was high. For switch trials, the main effect of *error likelihood of the performed task* was significant with lower accuracy on high error likelihoods ($b = -6.01$; $z = -2.14$; $p < .001$). The interaction of $error_{n-1}$ and *error likelihood of the performed task* was significant ($b = -2.16$; $z = -2.00$; $p = .045$) with post-error increases in accuracy on low error likelihoods but post-error decreases in accuracy on high error likelihoods. The interaction of *error likelihood of the performed task* and *error likelihood of the alternative task* was significant ($b = 6.01$; $z = 2.14$; $p = .031$) with increased accuracies when the error likelihood of the performed task was low, compared to high error likelihoods of the alternative task, and decreased accuracies when the error likelihood of the performed task was high, compared to high error likelihoods of the alternative task.

S1. Reaction time as a function of signal to noise level. The different signal to noise ratio levels 1 to 6 (or 8 for Experiment 1b) indicate increasing difficulty levels, that is, smaller signal to noise ratios. RTs were less affected from the level increases. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Left panel plots the reaction time of the color task. Right panel plots the reaction time of the motion task. Red dots indicate the average reaction time. Black dots indicate the RT of each individual for each level, respectively.

S2. Reaction time (in ms) as a function of error_{n-1}, error likelihood of the performed task, and error likelihood of the alternative task, for repetition trials and each experiment, respectively. The accuracy of the response on the previous trial is colored in red (error in n -1) and blue (correct in n-1). Error likelihoods of the performed task are depicted on the x-axis. Error likelihoods of the alternative task are indicated as panels. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard error.

S3. Reaction time (in ms) as a function of error_{n-1} , error likelihood of the performed task, and error likelihood of the alternative task, for switch trials and each experiment, respectively. The accuracy of the response on the previous trial is colored in red (error in $n-1$) and blue (correct in $n-1$). Error likelihoods of the performed task are depicted on the x-axis. Error likelihoods of the alternative task are indicated as panels. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard error.

S4. Accuracy (in %) as a function of error_{n-1}, error likelihood of the performed task, and error likelihood of the alternative task, for repetition trials and each experiment, respectively. The accuracy of the response on the previous trial is colored in red (error in n -1) and blue (correct in n-1). Error likelihoods of the performed task are depicted on the x-axis. Error likelihoods of the alternative task are indicated as panels. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard error.

S5. Accuracy (in ms) as a function of error_{n-1}, error likelihood of the performed task, and error likelihood of the alternative task, for switch trials and each experiment, respectively.

The accuracy of the response on the previous trial is colored in red (error in $n-1$) and blue (correct in $n-1$). Error likelihoods of the performed task are depicted on the x-axis. Error likelihoods of the alternative task are indicated as panels. Each row indicates one experiment (first row = Experiment 1a; second row = Experiment 1b; third row = Experiment 2). Colored lines indicate the model fits and shades indicate the standard error.

S6

Estimate (b), Standard Error (SE), t -Value, and p -Value for Each Fixed Effect (Intercept, $Error_{n-1}$, Error Likelihood of the Performed Task [$EL_{\text{performed task}}$], Error Likelihood of the Alternative Task [$EL_{\text{alternative task}}$], and Task Transition [TT]) Including Their Interactions on Reaction Time of Model 5 for Each Experiment, Respectively.

Fixed effects	Experiment 1a				Experiment 1b				Experiment 2			
	b	SE	t -value	p -value	b	SE	t -value	p -value	b	SE	t -value	p -value
Intercept	739.47	12.65	58.41	< .001	671.12	9.89	67.80	< .001	723.80	18.03	40.13	< .001
$Error_{n-1}$	24.82	7.37	3.36	< .001	18.39	4.34	4.23	< .001	14.61	7.69	1.89	.057
$EL_{\text{performed task}}$	-1.06	35.24	-0.03	.975	136.52	29.55	4.72	< .001	84.14	39.20	2.14	.032
$EL_{\text{alternative task}}$	-68.07	26.45	-2.57	.010	-12.45	24.55	-0.51	.606	-34.69	29.65	-1.17	.244
TT	33.47	8.15	4.10	< .001	35.89	5.38	6.66	< .001	17.78	8.82	2.01	.045
$Error_{n-1} \times EL_{\text{performed task}}$	-78.17	26.40	-2.96	.003	-55.22	16.62	-3.31	< .001	-16.44	30.15	-0.54	.585
$Error_{n-1} \times EL_{\text{alternative task}}$	-7.22	20.67	-0.34	.726	-17.62	14.20	-1.24	.214	-22.82	21.65	-1.05	.291
$Error_{n-1} \times TT$	-0.61	7.39	-0.08	.933	1.04	4.35	0.24	.810	-7.78	7.67	-1.01	.309
$EL_{\text{performed task}} \times EL_{\text{alternative task}}$	141.01	75.45	1.86	.061	88.49	64.77	1.36	.171	66.55	84.52	0.78	.431
$EL_{\text{performed task}} \times TT$	-42.97	27.23	-1.57	.114	-53.13	20.42	-2.60	.009	75.95	30.60	0.02	.980
$EL_{\text{alternative task}} \times TT$	-27.84	21.38	-1.30	.192	-4.25	16.46	-0.25	.796	18.65	22.02	0.84	.396
$Error_{n-1} \times EL_{\text{performed task}} \times EL_{\text{alternative task}}$	42.50	70.18	0.60	.544	95.29	55.89	1.70	.008	19.11	80.20	0.23	.811
$Error_{n-1} \times EL_{\text{performed task}} \times TT$	-14.05	26.44	-0.53	.595	-39.16	16.67	-2.34	.018	26.16	30.06	0.87	.384
$Error_{n-1} \times EL_{\text{alternative task}} \times TT$	-4.66	20.72	-0.22	.821	-37.68	14.21	-2.65	.008	8.11	21.60	0.37	.707
$EL_{\text{performed task}} \times EL_{\text{alternative task}} \times TT$	117.31	72.72	1.61	.106	102.18	63.17	1.61	.105	112.20	81.57	<.001	.999
$Error_{n-1} \times EL_{\text{performed task}} \times EL_{\text{alternative task}} \times TT$	40.62	70.21	0.57	.562	211.36	55.78	3.78	< .001	-43.40	79.97	-0.54	.587

Note. $\times$ Indicates the interaction of two variables.

S7

Estimate (b), Standard Error (SE), t -Value, and p -Value for Each Fixed Effect (Intercept, $Error_{n-1}$, Error Likelihood of the Performed Task [$EL_{performed\ task}$], Error Likelihood of the Alternative Task [$EL_{alternative\ task}$], and Task Transition [TT]) Including Their Interactions on Accuracy of Model 5 for Each Experiment, Respectively.

Fixed effects	Experiment 1a				Experiment 1b				Experiment 2			
	b	SE	z -value	p -value	b	SE	z -value	p -value	b	SE	z -value	p -value
Intercept	2.13	0.12	16.52	< .001	2.50	0.09	25.55	< .001	2.66	0.20	13.27	< .001
$Error_{n-1}$	-0.25	0.12	-1.99	.046	-0.22	0.09	-2.24	.024	0.03	0.20	0.17	.862
$EL_{performed\ task}$	-4.47	0.38	-11.64	< .001	-5.38	0.28	-18.70	< .001	-5.86	0.56	-10.45	< .001
$EL_{alternative\ task}$	-0.07	0.35	-0.21	.833	-1.08	0.29	-3.47	< .001	-0.62	0.52	-1.19	.233
TT	-0.22	0.12	-1.72	.084	-0.26	0.09	-2.67	.007	0.19	0.20	0.97	.327
$Error_{n-1} \times EL_{performed\ task}$	0.24	0.38	0.64	.519	0.42	0.28	1.48	.136	-0.55	0.56	-0.98	.325
$Error_{n-1} \times EL_{alternative\ task}$	0.02	0.35	0.06	.948	-0.07	0.29	-0.24	.807	-0.14	0.52	-0.27	.783
$Error_{n-1} \times TT$	0.23	0.12	1.82	.068	0.34	0.09	3.49	< .001	0.54	0.20	2.70	.006
$EL_{performed\ task} \times EL_{alternative\ task}$	0.24	1.02	0.24	.808	3.11	0.91	3.40	< .001	2.13	1.45	1.46	.142
$EL_{performed\ task} \times TT$	0.57	0.38	1.49	.135	0.96	0.28	3.35	< .001	-0.64	0.56	-1.14	.254
$EL_{alternative\ task} \times TT$	-0.50	0.35	-1.39	.162	-1.01	0.29	-3.48	< .001	-1.19	0.52	-2.29	.021
$Error_{n-1} \times EL_{performed\ task} \times EL_{alternative\ task}$	0.69	1.02	0.67	.497	0.95	0.91	1.04	.296	1.48	1.45	1.02	.307
$Error_{n-1} \times EL_{performed\ task} \times TT$	-0.82	0.38	-2.15	.031	-1.18	0.28	-4.11	< .001	-1.47	0.56	-2.63	.008
$Error_{n-1} \times EL_{alternative\ task} \times TT$	-0.62	0.35	-1.73	.082	-0.63	0.29	-2.19	.028	-1.17	0.52	-2.25	.023
$EL_{performed\ task} \times EL_{alternative\ task} \times TT$	1.04	1.02	1.02	.307	1.97	0.91	2.15	.031	3.67	1.45	2.53	.011
$Error_{n-1} \times EL_{performed\ task} \times EL_{alternative\ task} \times TT$	1.87	1.02	1.82	.065	2.85	0.91	3.12	.001	3.52	1.45	2.42	.015

Note. $\times$ Indicates the interaction of two variables.

Random Effects Experiment 1a***Task Choices***

A correlation of .02 of intercept and error_{n-1} suggested the number of task switches did not influence the effect of error_{n-1} . The random effects revealed a negative correlation of -.49 between intercept and error likelihood of the performed task, suggesting that participants with higher switch rates had a higher effect of error likelihood of the performed task on switch rates. A negative correlation of -.35 of intercept and alternative error likelihood was observed, suggesting that participants with high switch rates had a smaller effect of alternative error likelihood on task switches. There was a negative correlation of -.02 of error_{n-1} and error likelihood of the performed task suggesting that the effect of error likelihood of the performed task did not influence the effect of error_{n-1} . There was a negative correlation of -.23 of error_{n-1} and alternative error likelihood suggesting that participants with an increased effect of alternative error likelihood did show a reduced effect of error_{n-1} . A negative correlation of -.46 of error likelihood of the performed task and alternative error likelihood was observed, indicating that participants with a larger effect of error likelihood of the performed task had a smaller effect of the error likelihood of the alternative task.

Task Choice Latencies

A positive correlation of .17 of intercept and error_{n-1} suggested that participants with overall high task choice latencies used more time after incorrect responses compared to correct responses. The random results suggested that participants with high task choice latencies took more time to choose the task with increasing error likelihood of the performed task (correlation of .10 between intercept and error likelihood of the performed task). A negative correlation of -.59 of intercept and error likelihood of the alternative task suggested that participants with overall high task choice

latencies used less time with increasing error likelihood of the alternative task. A positive correlation of .85 of intercept and task transition suggested that participants with overall high task choice latencies used more time on switch choices, compared to repetition choices. A positive correlation of .26 of error_{n-1} and error likelihood of the performed task suggested that participants with high task choice latencies on high error likelihoods of the performed task also used more time after incorrect responses compared to correct responses. A positive correlation of .08 of error_{n-1} and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the alternative task also used more time after incorrect responses compared to correct responses. A positive correlation of .11 of error_{n-1} and task transition suggested that participants with high task choice latencies on switch trials compared to repetition trials used more time after incorrect responses compared to correct responses. A positive correlation of .39 of error likelihood of the performed task and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the performed task also used more time on high error likelihoods of the alternative task. A positive correlation of .33 of error likelihood of the performed task and task transition suggested that participants with high task choice latencies on high error likelihoods of the performed task also used more time on switch trials compared to repetition trials. A negative correlation of -.30 of error likelihood of the alternative task and task transition suggested that participants with high task choice latencies on high error likelihoods of the alternative task also used more time on switch trials compared to repetition trials

Reaction Time

A negative correlation of -.58 of intercept and error likelihood of the performed task suggested that participants with overall high task choice latencies revealed lower task choice

latencies on high error likelihoods of the performed task. A negative correlation of $-.65$ of intercept and error likelihood of the alternative task suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the alternative task. A positive correlation of $.10$ of intercept and task transition suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the alternative task. A positive correlation of $.30$ of error likelihood of the performed task and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the performed task revealed high task choice latencies on high error likelihoods of the alternative task. A negative correlation of $-.18$ of error likelihood of the performed task and task transition suggested that participants with high task choice latencies on high error likelihoods of the performed task revealed low task choice latencies on switch trials compared to repetition trials. A negative correlation of $-.26$ of error likelihood of the alternative task and task transition suggested that participants with high task choice latencies on high error likelihoods of the alternative task revealed low task choice latencies on switch trials compared to repetition trials.

Accuracy

For accuracy, the most complex model included fitting a random intercept for each subject. Thus, no random effects are reported.

Random Effects Experiment 1b

Task Choices

A correlation of $-.02$ of intercept and error_{n-1} suggested the number of task switches did not influence the effect of error_{n-1} . The random effects revealed a negative correlation of $-.26$ between intercept and error likelihood of the performed task, suggesting that participants with higher switch

rates had a higher effect of error likelihood of the performed task on switch rates. A correlation of .06 of intercept and alternative error likelihood suggested that the number of task switches did not influence the effect of error likelihood of the alternative task. A positive correlation of .10 of error_{n-1} and error likelihood of the performed task suggested that participants with an increased effect of error likelihood of the performed task also switch more after errors compared to correct responses. There was a negative correlation of -.30 of error_{n-1} and alternative error likelihood suggesting that participants with an increased effect of alternative error likelihood did show a reduced effect of error_{n-1} . A negative correlation of -.88 of error likelihood of the performed task and alternative error likelihood was observed, indicating that participants with a larger effect of error likelihood of the performed task had a smaller effect of the error likelihood of the alternative task.

Task Choice Latencies

A positive correlation of .38 of intercept and error_{n-1} suggested that participants with overall high task choice latencies used more time after incorrect responses compared to correct responses. A correlation of .01 of intercept and error likelihood of the performed task suggested no effect of participants' overall task choice latency on the effect of error likelihood of the performed task. A positive correlation of .12 of intercept and error likelihood of the alternative task suggested that participants with overall high task choice latencies used more time with increasing error likelihood of the alternative task. A positive correlation of .93 of intercept and task transition suggested that participants with overall high task choice latencies used more time on switch choices, compared to repetition choices. A negative correlation of -.18 of error_{n-1} and error likelihood of the performed task suggested that participants with high task choice latencies on high error likelihoods of the performed task used less time after incorrect responses compared to correct responses. A positive

correlation of .34 of error_{n-1} and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the alternative task used more time after incorrect responses compared to correct responses. A positive correlation of .33 of error_{n-1} and task transition suggested that participants with high task choice latencies on switch trials compared to repetition trials used more time after incorrect responses compared to correct responses. A negative correlation of -.59 of error likelihood of the performed task and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the performed task used less time on high error likelihoods of the alternative task. A positive correlation of .10 of error likelihood of the performed task and task transition suggested that participants with high task choice latencies on high error likelihoods of the performed task also used more time on switch trials compared to repetition trials. A positive correlation of .20 of error likelihood of the alternative task and task transition suggested that participants with high task choice latencies on high error likelihoods of the alternative task used less time on switch trials compared to repetition trials.

Reaction Time

A negative correlation of -.13 of intercept and error likelihood of the performed task suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the performed task. A negative correlation of -.63 of intercept and error likelihood of the alternative task suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the alternative task. A positive correlation of .19 of intercept and task transition suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the alternative task. A correlation of .06 of error likelihood of the performed task and error likelihood

of the alternative task suggested no effect of error likelihood of the performed task on error likelihood of the alternative task. A correlation of .07 of error likelihood of the performed task and task transition suggested no effect of error likelihood of the performed task on task transition. A negative correlation of -.68 of error likelihood of the alternative task and task transition suggested that participants with high task choice latencies on high error likelihoods of the alternative task revealed low task choice latencies on switch trials compared to repetition trials.

Accuracy

For accuracy, the most complex model included fitting a random intercept for each subject. Thus, no random effects are reported.

Random Effects Experiment 2

Task Choices

A correlation of .09 of intercept and error_{n-1} suggested the number of task switches did not influence the effect of error_{n-1} . The random effects revealed a negative correlation of -.46 between intercept and error likelihood of the performed task, suggesting that participants with higher switch rates had a higher effect of error likelihood of the performed task on switch rates. A correlation of .04 of intercept and alternative error likelihood suggested that the number of task switches did not influence the effect of error likelihood of the alternative task. There was a negative correlation of -.26 of error_{n-1} and error likelihood of the performed task suggesting that participants with an increased error likelihood of the performed task effect also switch more after an error compared to a correct response. There was a negative correlation of -.38 of error_{n-1} and alternative error likelihood and suggesting that participants with an increased effect of alternative error likelihood did show a reduced effect of error_{n-1} . A negative correlation of -.73 of error likelihood of the

performed task and alternative error likelihood was observed, indicating that participants with a larger effect of error likelihood of the performed task had a smaller effect of the error likelihood of the alternative task.

Task Choice Latencies

A negative correlation of .19 of intercept and error_{n-1} suggested that participants with overall high task choice latencies used less time after incorrect responses compared to correct responses. A negative correlation of -.28 of intercept and error likelihood of the performed task suggested that participants with overall high task choice latencies used less time with increasing error likelihood of the performed task. A negative correlation of -.11 of intercept and error likelihood of the alternative task suggested that participants with overall high task choice latencies used less time with increasing error likelihood of the alternative task. A positive correlation of .92 of intercept and task transition suggested that participants with overall high task choice latencies used more time on switch choices, compared to repetition choices. A negative correlation of -.42 of error_{n-1} and error likelihood of the performed task suggested that participants with high task choice latencies on high error likelihoods of the performed task used less time after incorrect responses compared to correct responses. A negative correlation of -.71 of error_{n-1} and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the alternative task also used less time after incorrect responses compared to correct responses. A negative correlation of -.43 of error_{n-1} and task transition suggested that participants with high task choice latencies on switch trials compared to repetition trials used less time after incorrect responses compared to correct responses. A positive correlation of .88 of error likelihood of the performed task and error likelihood of the alternative task suggested that participants with high task choice latencies on high error likelihoods of the performed task also

used more time on high error likelihoods of the alternative task. A negative correlation of $-.17$ of error likelihood of the performed task and task transition suggested that participants with high task choice latencies on high error likelihoods of the performed task used less time on switch trials compared to repetition trials. A correlation of $-.01$ of error likelihood of the alternative task and task transition suggested no correlation between these two factors.

Reaction Time

A negative correlation of $-.57$ of intercept and error likelihood of the performed task suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the performed task. A negative correlation of $-.66$ of intercept and error likelihood of the alternative task suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the alternative task. A positive correlation of $.37$ of intercept and task transition suggested that participants with overall high task choice latencies revealed lower task choice latencies on high error likelihoods of the alternative task. A correlation of $.64$ of error likelihood of the performed task and error likelihood of the alternative task suggested that participants with a high effect of error likelihoods of the performed task used more time on high alternative error likelihoods. A negative correlation of $-.31$ of error likelihood of the performed task and task transition suggested that participants with a high effect of error likelihoods of the performed task used more time on switch trials compared to repetition trials. A negative correlation of $-.52$ of error likelihood of the alternative task and task transition suggested that participants with high task choice latencies on high error likelihoods of the alternative task revealed low task choice latencies on switch trials compared to repetition trials.

Accuracy

For accuracy, the most complex model included fitting a random intercept for each subject. Thus, no random effects are reported.