Cogn Affect Behav Neurosci (2015) 15:365–373
DOI 10.3758/s13415-014-0321-8

# Reflexive activation of newly instructed stimulus–response rules: evidence from lateralized readiness potentials in no-go trials

**Nachshon Meiran · Maayan Pereg · Yoav Kessler · Michael W. Cole · Todd S. Braver**

**Abstract** Previous behavioral and electrophysiological evidence has suggested that the instructions for a new choice task are processed even when they are not currently required, indicating intention-based reflexivity. Yet these demonstrations were found in experiments in which participants were set to execute a response (go). In the present experiment, we asked whether intention-based reflexivity would also be observed under unfavorable conditions in which participants were set not to respond (no-go). In each miniblock of our paradigm, participants received instructions for a task in which two new stimuli were mapped to right/left keys. Immediately after the instructions, a no-go phase began, which was immediately followed by a go phase. We found a significant stimulus-locked lateralized readiness potential in the first no-go trial, indicating reflexive operation of the new instructions. These results show that representing instructions in working memory provides sufficient conditions for stimuli to launch task processing, proceeding all the way until motor response-specific brain activation, which takes place even under unfavorable, no-go conditions.

**Keywords** Instructions · LRP · Intention-based reflexivity · Working memory · Automaticity

N. Meiran (✉) · M. Pereg · Y. Kessler
Department of Psychology and Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel
e-mail: nmeiran@bgu.ac.il

M. W. Cole
Center for Molecular and Behavioral Neuroscience, Rutgers University, Rutgers, NJ, USA

T. S. Braver
Department of Psychology, Washington University, St. Louis, MO, USA

What happens when one is performing a task for the first time? Current theories agree that goal-directed performance is based on limited-capacity abilities that involve the prefrontal cortex and are collectively described as “working memory” (Miller & Cohen, 2001). What characterizes task performance at this early stage is slowness and error proneness. This literature suggests that extensive practice is required for performance to become efficient, by enabling its execution via associations in the capacity-*un*limited long-term memory (Anderson, 1982; Logan, 1988, 1992; Rosenbloom & Newell, 1986; Shiffrin & Schneider, 1977). An interesting question is *what happens when there is no prior opportunity for training (i.e., on first-time performance), but the task must still be carried out efficiently and effectively?* This demand presents itself frequently in modern life—for example, when following road directions. Yet similar demands probably existed long ago in the course of human evolution; when humans needed to instruct one another on the fly in collaborative tasks such as hunting, success depended on the ability to quickly assimilate the new instructions.

In recent years, there has been growing interest in the ability to immediately and successfully follow new instructions. Neuroimaging studies have indicated the involvement of lateral prefrontal cortex (LPFC), posterior parietal cortex (PPC), and basal ganglia in instructional task control (Cole, Laurent, & Stocco, 2013). These regions are part of a larger network or region—the frontoparietal control system—activated across a wide variety of cognitive control demands (Cole & Schneider, 2007; Duncan, 2010). Previous results focusing on the instruction and initial task execution stages showed that all components of the frontoparietal control system were involved (Dumontheil, Thompson, & Duncan, 2011). Critically, however, that study did not control for the overall working memory load of the task, failing to isolate task novelty from the broader load manipulation. Several studies that did carefully isolate the effect of task novelty—effectively controlling for working memory load—showed that only portions of LPFC, PPC, and basal ganglia were sensitive to the initial task instruction and execution (Cole, Bagic, Kass, & Schneider, 2010; Ruge & Wolfensteller, 2010; Stocco, Lebiere, O'Reilly, & Anderson, 2012).

Modeling work (Bugmann, 2012; Huang, Hazy, Herd, & O'Reilly, 2013; Ramamoorthy & Verguts, 2012; see also Logan, 1988) has suggested that goal-directed behavior can rely on two processing routes. One route operates slowly, is computationally complex, and involves the prefrontal cortex, hippocampus, and basal ganglia (Huang et al., 2013) or the temporal and premotor cortex (Ramamoorthy & Verguts, 2012). According to these authors, the slow route subserves performance based on mere instructions, and the second route involves the parietal and motor cortex (Huang et al., 2013) or the cortico-striato-pallido-thalamo-cortical pathway (Ramamoorthy & Verguts, 2012). Performance subserved by the latter route is relatively rapid, based on learning that occurred during prior task execution. Thus, when executing a practiced task, both routes may take control. However, in a newly instructed task, only the slow route can be utilized.

The present work focuses on an important feature of newly instructed tasks—their autonomous processing, which has primarily been examined so far in purely behavioral studies. *Process autonomy* indicates that, once the process has been launched, it proceeds without monitoring. Such autonomy is observed when the instructions provided for a novel task (the *inducer* task) influence the performance in another, familiar task (the *diagnostic* task; Cohen-Kdoshay & Meiran, 2007, 2009; De Houwer, Beckers, Vandorpe, & Custers, 2005; Liefooghe, De Houwer, & Wenke, 2013; Liefooghe, Wenke, & De Houwer, 2012; Meiran & Cohen-Kdoshay, 2012; Wenke, Gaschler, & Nattkemper, 2007; Wenke, Gaschler, Nattkemper, & Frensch, 2009). For example, Meiran, Pereg, Kessler, Cole, and Braver (in press) designed a "NEXT" paradigm consisting of several dozen miniblocks. In each miniblock, participants were given instructions for a new two-choice task in which two new stimuli were assigned to a right or left keypress. Following the instructions, the stimuli were presented at the center of the screen in *red* color, and participants were instructed *not* to apply the instructions and simply to advance the screen (NEXT responses) by pressing the right key (or the left key, for the other half of the participants). As soon as the stimuli started appearing in *green*, participants had to apply the instructions ("go" responses). The main result indicated slower NEXT responses to stimuli that were assigned to the opposite key, indicating a *NEXT compatibility effect.*

Process autonomy has mostly been discussed as a component of skill-based automaticity (Moors & De Houwer, 2006; cf. Bargh 1992; Tzelgov, 1997). We (Meiran, Cole, & Braver, 2012) labeled the autonomy that characterizes newly instructed tasks "intention-based reflexivity," to denote the fact that it represents a different phenomenon than skill-based automaticity. To account for intention-based reflexivity, Meiran et al. (in press) argued that performance that immediately follows instructions relies on fragile representations (see, especially, Cole et al., 2013) that are highly susceptible to interference. To ensure the integrity of these representations, as is required for efficient performance, irrelevant information must be blocked. Yet blocking is associated with a downside, a reduced ability to change the behavioral plan on the fly, as is seen in the phenomenon of intention-based reflexivity.

In the present work, we asked whether intention-based reflexivity would also be observed under conditions that are highly challenging for autonomy to be observed. Specifically, it has been argued that autonomy depends on the task set, which is the activated knowledge that is required for task execution. For example, in Besner and Risko's (2005) dual-task experiments, the inducer task was a highly compatible and skilled task in which participants had to react to the right–left position of a stimulus by pressing the right/left key. A tone indicated whether the current trial was a go or a no-go trial. The results indicated autonomous processing of stimulus position only in go trials that followed other go trials, but not in go trials that followed no-go trials. These results indicate that go (vs. no-go) is a part of the task set, and that being set to go (by performing a go trial in the immediately preceding trial) may be essential for autonomy to be observed (cf. Verbruggen & Logan, 2009). More generally, the argument is that autonomy is a matter of degree (e.g., Moors & De Houwer, 2006), and a greater degree of autonomy would be indicated when it is observed under an unfavorable task set (no-go). The degree to which a task set is favorable depends on the shared features between the diagnostic and inducer tasks (Ganor-Stern, Tzlegov, & Meiran, 2013; Hommel, 2000; Kornblum, Hasbroucq, & Osman, 1990). Moreover, some task features, such as the go feature, seem especially important in this regard.

In the present work, we varied Meiran et al.'s (in press) NEXT paradigm so that intention-based reflexivity could be observed even under the challenging conditions in which participants are set to no-go. We therefore replaced the NEXT phase by a no-go phase, in which participants had to withhold responding altogether. In our paradigm, participants received a novel choice task in every miniblock (see Fig. 1). After the instructions were given, the stimuli were presented in *red* color in an initial, no-go phase. This no-go phase ended at an unexpected point in time, and a brief go phase followed in which the stimuli appeared in *green* color. This go phase included only two trials, and the participants were strongly encouraged to respond quickly and accurately in these trials. This requirement implied that participants would need to be highly prepared on the basis of the instructions alone, given the lack of opportunity to practice the task. When the miniblock ended, a new miniblock began with a new set of stimuli and stimulus–response (S–R) instructions.

In order to observe intention-based reflexivity, we measured the right-/left-hand motor activation during the no-go phase. We did so by using event-related potentials (ERP) and by focusing on the stimulus-locked lateralized readiness potential (sLRP), which is an ERP waveform signaling the preparation of a motor response (Coles, 1989; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Smulders & Miller, 2012). The sLRP is usually computed as the difference in negativity observed over the contralateral versus the ipsilateral motor cortex, relative to the *responding* hand. Since responding was completely withheld during the no-go phase, instead of defining the sLRP in terms of responding hand, we defined it in terms of the hand that, according to the novel task instructions, would be used for responding, had this been a go trial. We predicted a significant sLRP in the no-go phase, a result that would indicate that the presentation of the stimuli was sufficient to launch the processing of the new instructions up to the level of response selection, including partial motor activation of the instructed response. Measuring a sLRP in the first no-go trial was the most critical test, since this was the trial that immediately followed the instructions. We also measured the sLRP in the go phase. This go sLRP was computed in the usual way. The latter sLRP provided a comparison for the critical no-go sLRP.

Previous studies have already shown an sLRP to *stimuli* that were not responded to beforehand. For example, Eimer and Schleghecken (1998; see Eimer & Schlaghecken, 2003, for a review) showed sLRP for subliminally presented stimuli. Similarly, an sLRP to supraliminally primed responses has been found even in the no-go trials in a go/no-go paradigm, despite the lack of an overt response (Kopp, Mattler, Goertz, & Rist, 1996). The aforementioned studies do not answer our question, however, because the sLRP was observed in experiments in which the inducer *task* (as opposed to stimuli) was repeatedly executed. Recently, Everaert, Theeuwes, Liefooghe, and De Houwer (in press) used a task-switching design in which two tasks were performed using the same stimuli. One task was constant throughout the experiment and was performed in the first trials of each miniblock, and the other task was newly instructed in each miniblock and was performed in the last trials of the miniblock. Consequently, participants had to hold the new instructions in mind while executing the constant task, during which LRP was recorded. The results showed that the LRP initially shifted in the direction of the response indicated by the newly instructed task. Moreover, even afterward, when the LRP was in the expected direction, its amplitude was attenuated in trials in which the newly instructed task generated response competition. Although it is highly relevant to our study, the LRP in Everaert et al.'s study was recorded while participants executed another task—namely, under conditions that might favor intention-based reflexivity. The contribution of the present experiment was in measuring sLRP related to a newly instructed inducer task in a no-go condition. Finding an sLRP in this condition, despite the unfavorable no-go setting, would imply a high degree of autonomy of newly instructed tasks.

## Method

### Participants

Thirty-two Ben-Gurion University undergraduate students took part in the experiment in return for an introductory course credit or for monetary compensation (NIS80–100, ~$23–$28) (17 males, 15 females; mean age = 23.87 years, *SD* = 1.63). All of the participants reported having normal or corrected-to-normal vision including intact color vision, and not having diagnosed attention deficits. Three participants were excluded for showing no indication of sLRP in the go condition, and six were excluded for having more than 30 % artifacts in one or more of the conditions, leaving us with the results of 23 participants.

### Materials and procedure

Participants sat about 60 cm away from a 17-in. monitor that was controlled by a desktop computer, with software written in E-Prime 2.0 (Schneider, Eschman, Zuccolotto, 2012). The 220 stimuli consisted of 26 English letters, ten digits, 24 Hebrew letters,[1] 20 symbols (e.g., arithmetic symbols), and 140 pictures (e.g., shapes and different objects). The letters, symbols, and most of the pictures came from Microsoft PowerPoint symbol pool, and the rest of the pictures were sketches drawn from free Internet image search databases. The size of the stimuli was 3 × 3 cm, digits and letters appeared in a Calibri font. The two new stimuli that were chosen in each choice task came from the same stimulus group (e.g., two digits, two pictures). Within each category, the stimuli were chosen pseudorandomly without replacement, so that each stimulus was used only once in the course of the experiment.

The paradigm (see Fig. 1) consisted of 110 two-choice tasks. Each task involved two stimuli that were arbitrarily mapped to a right and a left key (L and A on a QWERTY keyboard, respectively). Each miniblock consisted of an instruction screen for a new choice task, followed by zero to five no-go trials (see below), then a go phase that consisted of only two trials, and finally a feedback screen reporting the accuracy and reaction time (RT) in the given choice task.

During the instruction screen, two stimuli were presented, one on the right and the other on the left (each stimulus center was placed 15.5 cm from the center of the screen). This

---

[1] The Hebrew alphabet has only 22 letters, but some of the letters have a different shape when they come at the end of a word, a fact that enabled us to slightly increase the number of stimuli.

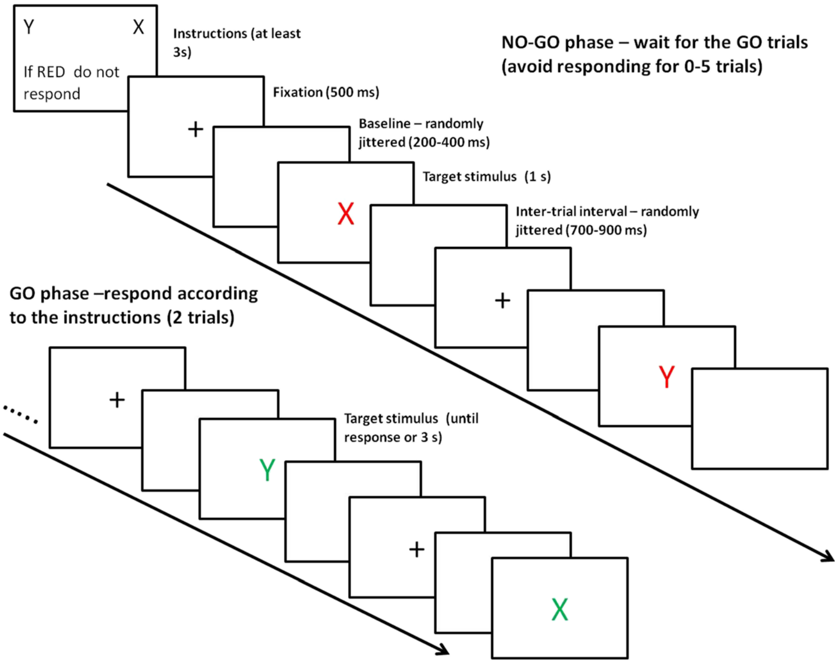

**Fig. 1** Participants (a) first received instructions regarding the go phase; (b) in an initial no-go phase, avoided responding (zero to five trials); and (c) in the go phase, executed the instructions (two trials)

indicated that the stimulus on the right was mapped to the right response key (L), whereas the stimulus on the left was mapped to the left response key (A). The participants were required to place their fingers on the response keys and be ready to execute the go task. They had to press the spacebar when they were ready to perform the task, but not sooner than 3 s from the onset of the instructions screen. In order to maximize motivation, participants were told that the two participants exhibiting the best (go) performance would get bonus credit points or an additional payment.

The no-go phase preceded the go phase. The phases were made visually discriminable by means of the color in which the stimulus appeared. If the stimulus was presented in *red*, this indicated a no-go trial. If the stimulus was presented in *green*, this indicated a go trial, which required highly accurate and quick responding according to the instructions (see Fig. 1). In the no-go phase, a 500-ms fixation preceded a baseline interval that was randomly jittered between 200 and 400 ms, and then the stimulus was presented for 1 s. The same was true for the go phase, except that the target was presented until the participant responded or until 3 s had elapsed. In both phases, a black screen was shown after the target stimulus for a jittered intertrial interval randomized between 700 and 900 ms. Thus, the stimulus onset asynchrony was 2,400–2,800 ms in the no-go phase, and depended on RT in the go phase (but was not longer than 4,400–4,800 ms, in case the participant did not respond).

When the no-go phase ended, there were only two go trials, and then the next miniblock began. Three miniblocks were used for familiarization. We varied the length of the no-go phase (zero, one, and five trials) during this familiarization stage, to expose participants to this variability. The familiarization stage was followed by 11 identical task blocks, each consisting of ten miniblocks (110 miniblocks in total). Within each block, one, three, two, two, one, and one of the miniblocks had each of the no-go lengths from 0 through 5, respectively. If the participant made an error by responding during the no-go phase, the instructions were presented again, and the participant had to re-perform the same miniblock. These instances were later omitted from the analyses and occurred only 33 times in the entire experiment.

## EEG recording and analysis

A continuous electroencephalogram (EEG) was recorded from 64 scalp electrodes placed according to the International 10–20 System layout using an electrode cap (BioSemi Active Two 64-electrode system). Additional electrodes were placed below the left eye to measure vertical electro-oculogram (EOG) activity, and at the outer canthi of the right and left eyes in order to measure horizontal EOGs. All of the channels were referenced offline to the mastoid channels. These data were recorded using a 0.01- to 100-Hz bandpass filter. Signals were collected at 512 Hz and digitized with a 24-bit A/D converter.

The EEG data were processed using EEGLAB (Delorme & Makeig, 2004) and ERPLAB. A 30-Hz low-pass filter was applied, and the output was segmented from 100 ms prior to the stimulus presentation to 900 ms post-stimulus-presentation. The segments underwent an automatic artifact rejection of faulty channels, saccades, and eyeblinks, and were also subjected to manual verification. We set an a priori criterion to exclude participants with 30 % artifacts (or more). Segments with artifact detection and faulty channels were interpolated, and the segments were then averaged, re-referenced to the mastoid electrode, and baseline-corrected to 100 ms prestimulus.

### Data analysis

The epoched ERP segments for miniblocks with correct go trials were averaged according to the conditions of the analysis reported above. In order to reduce the number of statistical comparisons and prevent $\alpha$ inflation, we used the following procedure in the stimulus-locked analysis.

*Determining epochs of interest* We examined the difference between the C3 and C4 electrodes, in which the sLRP is typically observed (Smulders & Miller, 2012). On the basis of common practice in the prior literature, we initially set the epoch of interest to be between 200 and 400 ms (e.g., Luck, 2005). We down-sampled the data to 256 Hz by averaging adjacent sample pairs, in order to form fewer and more reliable samples. The sLRP (averaged across hands) was calculated at each of the resulting time points according to Coles (1989), using the data from left- and right-hand trials: sLRP = $[\text{Mean}(C4 - C3)_{\text{left}} + \text{Mean}(C3 - C4)_{\text{right}}]/2$. A series of $t$ tests determined whether the sLRPs at each time point differed significantly from zero. This was done separately in four conditions: the 1st and 2nd go trials, the 1st no-go trial, and the remaining no-go trials (pooled). We adopted Guthrie and Buchwald's (1991) procedure, which safeguards against $\alpha$ inflation due to running significance tests on each time sample. In this procedure, an epoch is declared significant only if a minimal number of consecutive time samples show significant $t$ tests. This minimal number depends on the sample size, number of time samples tested, and autocorrelation. We assumed an autocorrelation of .90 (the most conservative estimate in Guthrie & Buchwald's, 1991, tables) for one-sided $t$ tests (since we predicted a negative sLRP).

## Results

### Behavioral results from the go phase

Both RTs and percent errors (PEs) were analyzed in two-way analyses of variance, with the within-subjects independent variables no-go length (0–5), which indicated the number of no-go trials preceding the go trials, and go trial (1st vs. 2nd; Fig. 2). In RTs, both the no-go length main effect [$F(5, 110) = 5.17$, $MSE = 425.72$, $p < .001$, $\eta_p^2 = .19$] and the go trial main effect [$F(1, 22) = 83.76$, $MSE = 2{,}883.30$, $p < .0001$, $\eta_p^2 = .79$] were significant. The two-way interaction was also significant [$F(5, 110) = 12.20$, $MSE = 585.01$, $p < .0001$, $\eta_p^2 = .36$], indicating that the go trial effect was largest when there were no preceding no-go trials. This could reflect the fact that this condition was probably the least expected condition (10 %).

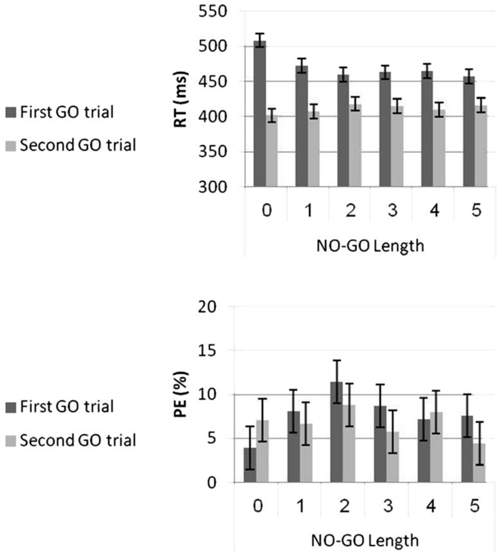

**Fig. 2** Go performance as a function of go trial and of the length of the no-go phase that preceded it, measured in both reaction times (RTs, in milliseconds; top panel) and percent errors (PE; bottom panel). Error bars represent within-subjects confidence intervals (Hollands & Jarmasz, 2010; Jarmasz, & Hollands, 2009)

In PEs, we found a marginally significant main effect of no-go length [$F(5, 110) = 2.15$, $MSE = 0.005$, $p = .06$, $\eta_p^2 = .09$] and a marginally significant interaction [$F(5, 110) = 2.13$, $MSE = 0.003$, $p = .07$, $\eta_p^2 = .09$].

### sLRP

An inspection of the results indicated a difference between the 1st no-go trial and the remaining no-go trials. Moreover, the 1st no-go trial was most critical, since it was the trial immediately following the instructions (Cohen-Kdoshay & Meiran, 2009). For these reasons, the 1st no-go trial and the remaining no-go trials were treated separately.

The a-priori epoch of interest was 200–400 ms. Nonetheless, visual inspection of the go phase results (Fig. 3) indicated that the sLRP window should be enlarged to 200–500 ms. This increase in the number of time samples required a related increase in the required number of consecutive significant time samples in order to declare significance (from 9 to 12). Within the new epoch of interest, the time window between 233 and 500 ms was significant for the 1st go trial (67 consecutive significant time samples) and between 200 and 476 ms (69 consecutive significant time samples) for the 2nd go trial.

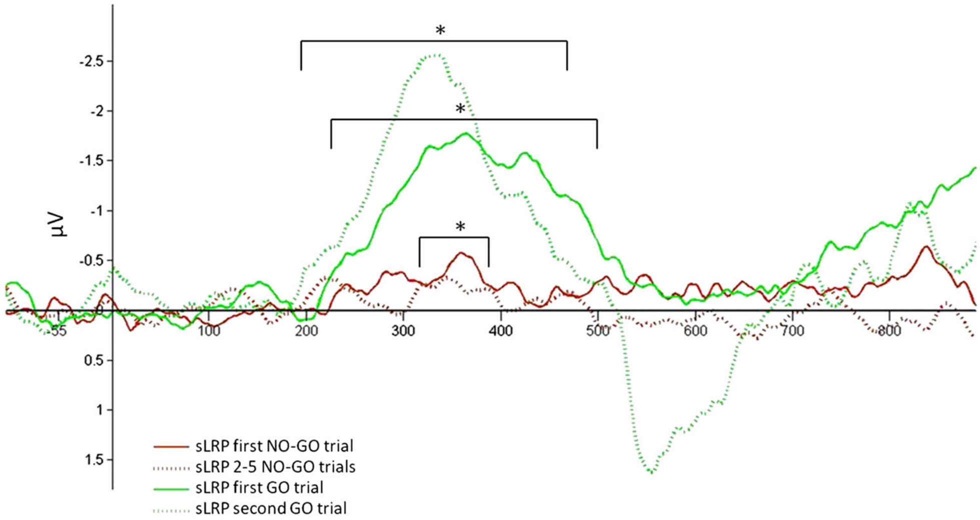

**Fig. 3** Grand average waveforms of the stimulus-locked lateralized readiness potential (sLRP), calculated as [Mean(C4 – C3)$_{\mathrm{left}}$ + Mean(C3 – C4)$_{\mathrm{right}}$]/2. Asterisks indicate the time windows over which the sLRP was significant within the 200- to 500-ms epoch

Critically, for the 1st no-go trial, a significant sLRP emerged between 329 and 380 ms (13 consecutive significant epochs). No significant sLRP was found for the remaining no-go trials (pooled). In order to compare sLRPs between the go and the 1st no-go trial, we averaged their amplitudes in the time window in which they were significant. The no-go sLRP (mean amplitude = –0.44 $\mu$V) was significantly smaller that the sLRPs of both the 1st and 2nd go trials (mean amplitudes = –1.26 and –1.39 $\mu$V, respectively), $t$s(22) = 3.06 and 3.67, respectively. Nonetheless, the significant epoch of the no-go sLRP more or less coincided with the epoch in which the 1st go sLRP reached its peak, suggesting that it represents a similar phenomenon.

### Correlations between no-go sLRP and go performance (Fig. 4)

If the no-go sLRP reflects preparation, then a larger (i.e., more negative) sLRP should predict better (i.e., quicker) go performance, predicting a positive correlation. We chose the difference in RTs between the 1st and the 2nd go trials as the measure of go performance immediately following the instructions. Our rationale was that the 2nd go trial provides a reasonable baseline for the speed achieved after having performed the task (once) or, alternatively, when the go task becomes certain. A smaller go trial effect reflects better preparation toward the 1st go trial. We excluded from the analysis those miniblocks in which there were zero no-go trials, to make sure that the sLRP and go performance were taken from the same miniblocks. The correlation of this measure with the no-go sLRP mean amplitude was positive, as predicted ($r$ = .39, $p$ = .035, one-sided; see Fig. 4).

## Discussion

Previous demonstrations of intention-based reflexivity (Cohen-Kdoshay & Meiran, 2007, 2009; De Houwer et al., 2005; Everaert et al., in press; Liefooghe et al., 2013; Liefooghe et al., 2012; Wenke et al., 2007; Wenke et al., 2009) had been obtained under favorable conditions, in which participants were set to go (Besner & Risko, 2005). In the present work, we asked whether intention-based reflexivity would also be observed under unfavorable conditions, in which participants were set to withhold responding in a no-go phase. Similar conditions have been shown to eliminate any evidence for autonomous processing of a highly skilled task (Besner & Risko, 2005). Consequently, we asked whether they would also eliminate evidence for autonomous processing of a newly instructed task ("intention-based reflexivity"). To this end, we measured the sLRP immediately following the instructions, in the no-go phase that preceded overt task execution (go).

Most participants (23 out of 26) showed a negative sLRP in the go trials. Although this result is somewhat secondary

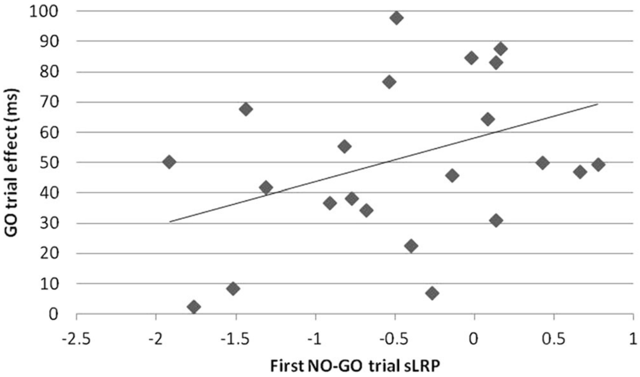

**Fig. 4** Correlation between the 1st no-go sLRP and the go trial effect (1st go RT minus 2nd go RT, in milliseconds): $r$ = .39

regarding our focus, it is still somewhat interesting, since it shows that typical sLRP effects can occur even when performing a novel task (instructed S–R mapping) for the first time. This contrasts with sLRPs reported in the literature in which the task has been repeatedly executed. Moreover, the amplitude of this go sLRP could help assess the size of the no-go sLRP, which was the critical finding.

Of greatest interest was that participants showing sLRP in the go trials also showed a significant sLRP in the 1st no-go trial, despite being told to withhold responding and despite not responding overtly. This result indicates intention-based reflexivity. The fact that evidence for intention-based reflexivity was found under conditions similar to those in which skill-based autonomous processing was not observed (Besner & Risko, 2005) is especially interesting. Yet this fact should be interpreted cautiously, given that the two studies employed very different methodologies. The no-go sLRP was smaller in amplitude and lasted for a shorter period of time than did the go sLRP, suggesting that motor activation in the no-go phase was only partial. Importantly, the no-go sLRP peaked more or less in the same time window as did the 1st go sLRP, suggesting that it represents a similar phenomenon. Interestingly, participants showing a large no-go sLRP also showed smaller go trial effects, suggesting that the no-go sLRP indexes task readiness.

Two anonymous reviewers noted that participants could have covertly practiced the tasks after receiving the instructions, and this could lead to partial automatization of the task. On the basis of literature that has suggested that automaticity requires extensive practice, the very limited opportunity given for covert practice in the present experiment was unlikely to have led to automaticity (as it has been studied in the skill acquisition literature). One way to show that performance was not automatized would be to examine go performance. We observed slower 1st than 2nd go responses, a finding that already suggests that initial task performance was not as efficient as the performance that followed (at least one) task execution. Two additional factors could have contributed to this effect. One was the change from a no-go to a go set (e.g., Verbruggen, Logan, Liefooghe, & Vandierendonck, 2008). The other factor was that the 2nd go trial was predictable, whereas the 1st go trial was unpredictable. Finally, performance involved a relatively high error rate and was poorer than is typically seen after extensive practice.

We suggest that intention-based reflexivity characterizes proactive (as opposed to reactive) control (Braver, 2012). According to Braver's theory, cognitive control can operate in either one of two modes. When in proactive mode, goal-related information is maintained in a sustained manner, and when in reactive mode, goal-related adjustments are performed when needed. Importantly, "proactive control relies upon the anticipation and *prevention* of interference before it occurs, whereas reactive control relies upon the *detection* and resolution of interference after its onset" (p. 106, emphases added). Thus, we have further suggested (see, e.g., Meiran et al., 2012) that proactive control is characterized by rigidity that results from the need to shield performance from distraction. This is achieved by a gating function, believed to involve interactions between the midbrain dopamine system and lateral PFC, and is potentially mediated through the basal ganglia (Frank & O'Reilly, 2006). Such a gating mechanism might be utilized to prevent new input from influencing the contents of working memory (Frank & O'Reilly, 2006) or to prevent an updated plan from influencing motor behavior (Chatham, Frank, & Badre, 2014). This shielding mode results in intention-based reflexivity, which reflects a difficulty with fully taking into account the current no-go requirement. This difficulty exists because the no-go requirement lasts at maximum only a few trials and also ends unpredictably.

A limitation of the present study is that we did not record the processes that took place when participants encoded the instructions (behaviorally or via measuring brain activity). From Meiran et al. (in press, Exp. 3), we know that it takes participants about 5 s to indicate their readiness to execute a task after seeing the instructions for the first time. This period seems too short to replace the extensive task practice that has been shown to produce automaticity. In fact, the same study showed that eight trials of actual task execution (roughly the number of trials one could covertly execute during a 5-s period) did not significantly change the size of the NEXT compatibility effect (which served as the index for intention-based reflexivity). Thus, it seems more plausible that instruction encoding led to the formation of a stable representation in working memory, possibly through some form of rehearsal and imagined task execution. Nevertheless, it will be important to demonstrate this process of working memory formation more directly in future work.

Another potential limitation of the present study relates to studies (some of which have measured LRPs) showing that *imagined* task execution leads to motor activation (Munzert, Lorey, & Zentgraf, 2009, for a review). It is therefore conceivable that our participants intentionally (rather than reflexively) imagined responding during the no-go phase while still complying with the no-go requirement. This alternative account is unlikely to be correct, for two main reasons. First, the aforementioned LRP studies employed tasks with familiar, highly compatible, and nonarbitrary S–R mappings. For example, Carrillo-de-la-Peña, Galdo-Álvarez, and Lastra-Barreira (2008), Carrillo-de-la-Peña, Lastra-Barreira, and Galdo-Álvarez (2006), Galdo-Álvarez and Carrillo de la Peña (2004), and Kranczioch, Mathews, Dean, and Sterr (2009) all used right-/left-pointing arrow stimuli to indicate the responding hand. Similarly, Hohlefeld, Nikulin, and Curio (2011), who focused on a measure resembling LRP, used the letters "R" and "L" to cue right-/left-hand responses. In contrast, we have studied tasks with *arbitrary* mappings that must have been initially maintained in working memory (Shahar, Teodorescu, Usher, Pereg, & Meiran, in press). Thus, it is difficult to know from these studies whether motor imagery is associated with LRP, even when it is triggered by newly instructed stimuli bearing an arbitrary relation to the imagined movement. Second, if participants intentionally imagined responding when seeing the stimuli in the no-go phase, sLRPs should have been observed throughout the no-go phase. Accordingly, it is unclear why the no-go sLRP was seen only in the 1st no-go trial and disappeared in the later (2nd and further) no-go trials. We argue that this result is more compatible with the interpretation that seeing the stimulus in the 1st no-go trial elicited reflexive motor preparation that participants quickly learned to overcome. In this regard, Meiran et al. (in press) used a NEXT paradigm, very similar to the present paradigm, in which instead of withholding a response in the no-go phase, participants had to advance the screen, and did so using one of the keys that was then used in the go phase (NEXT responses). In their 2nd experiment, they compared three stimulus types: compatible (in which the NEXT response was the same as the to-be performed go response), incompatible (in which the stimulus indicated the opposite response), and neutral (stimuli that were presented during the instructions but were not linked to any response). The authors observed slowing in the incompatible as compared to the neutral condition. This result too suggests reflexive activation of the incompatible response and is difficult to explain by referring to intended motor imagery.

In conclusion, in this study we have shown evidence that a newly instructed task was processed to the level of response selection, including initial motor activation, under conditions in which participants were set to no-go. This finding indicates intention-based reflexivity under a highly unfavorable task setting.

**Author Note** This research was supported by a research grant from the USA–Israel Bi-national Science Foundation to the first and last authors. We thank Florian Waszak for a stimulating discussion that was instrumental in generating this line of research.

## References

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89,* 369–406. doi:10.1037/0033-295X.89.4.369

Bargh, J. A. (1992). The ecology of automaticity: Toward establishing the conditions needed to produce automatic processing effects. *American Journal of Psychology, 105,* 181–199.

Besner, D., & Risko, E. F. (2005). Stimulus–response compatible orienting and the effect of an action not taken: Perception delayed is automaticity denied. *Psychonomic Bulletin and Review, 12,* 271–275. doi:10.3758/BF03196371

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16,* 106–113. doi:10.1016/j.tics.2011.12.010

Bugmann, G. (2012). Modeling fast stimulus–response association learning along the occipito-parieto-frontal pathway following rule instructions. *Brain Research, 1434,* 73–89. doi:10.1016/j.brainres.2011.09.028

Carrillo-de-la-Peña, M. T., Galdo-Álvarez, S., & Lastra-Barreira, C. (2008). Equivalent is not equal: Primary motor cortex (MI) activation during motor imagery and execution of sequential movements. *Brain Research, 1226,* 134–143.

Carrillo-de-la-Peña, M. T., Lastra-Barreira, C., & Galdo-Álvarez, S. (2006). Limb (hand vs. foot) and response conflict have similar effects on event-related potentials (ERPs) recorded during motor imagery and overt execution. *European Journal of Neuroscience, 24,* 635–643.

Chatham, C. H., Frank, M. J., & Badre, D. (2014). Corticostriatal output gating during selection from working memory. *Neuron, 81,* 930–942. doi:10.1016/j.neuron.2014.01.002

Cohen-Kdoshay, O., & Meiran, N. (2007). The representation of instructions in working memory leads to autonomous response activation: Evidence from the first trials in the flanker paradigm. *Quarterly Journal of Experimental Psychology, 60,* 1140–1154.

Cohen-Kdoshay, O., & Meiran, N. (2009). The representation of instructions operates like a prepared reflex: Flanker compatibility effects found in first trial following S–R instructions. *Experimental Psychology, 56,* 128–133. doi:10.1027/1618-3169.56.2.128

Cole, M. W., Bagic, A., Kass, R., & Schneider, W. (2010). Prefrontal dynamics underlying rapid instructed task learning reverse with practice. *Journal of Neuroscience, 30,* 14245–14254. doi:10.1523/JNEUROSCI.1662-10.2010

Cole, M. W., Laurent, P., & Stocco, A. (2013). Rapid instructed task learning: A new window into the human brain's unique capacity for flexible cognitive control. *Cognitive, Affective, & Behavioral Neuroscience, 13,* 1–22. doi:10.3758/s13415-012-0125-7

Cole, M. W., & Schneider, W. (2007). The cognitive control network: Integrated cortical regions with dissociable functions. *NeuroImage, 37,* 343–360. doi:10.1016/j.neuroimage.2007.03.071

Coles, M. G. H. (1989). Modern mind-brain reading: Psychophysiology, physiology, and cognition. *Psychophysiology, 26,* 251–269.

De Houwer, J., Beckers, T., Vandorpe, S., & Custers, R. (2005). Further evidence for the role of mode-independent short-term associations in spatial Simon effects. *Perception & Psychophysics, 67,* 659–666. doi:10.3758/BF03193522

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134,* 9–21. doi:10.1016/j.jneumeth.2003.10.009

Dumontheil, I., Thompson, R., & Duncan, J. (2011). Assembly and use of new task rules in fronto-parietal cortex. *Journal of Cognitive Neuroscience, 23,* 168–182. doi:10.1162/jocn.2010.21439

Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: Mental programs for intelligent behaviour. *Trends in Cognitive Sciences, 14,* 172–179. doi:10.1016/j.tics.2010.01.004

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1737–1747.

Eimer, M., & Schlaghecken, F. (2003). Response facilitation and inhibition in subliminal priming. *Biological Psychology, 64,* 7–26. doi:10.1016/S0301-0511(03)00100-5

Everaert, T., Theeuwes, M., Liefooghe, B., & De Houwer, J. (in press). Automatic motor activation by mere instruction. *Cognitive, Affective, & Behavioral Neuroscience.* doi:10.3758/s13415-014-0294-7

Frank, M. J., & O'Reilly, R. C. (2006). A mechanistic account of striatal dopamine function in human cognition: Psychopharmacological studies with cabergoline and haloperidol. *Behavioral Neuroscience, 120,* 497–517.

Galdo-Álvarez, S., & Carrillo de la Peña, M. T. (2004). ERP evidence of MI activation without motor response execution. *NeuroReport, 15,* 2067–2070.

Ganor-Stern, D., Tzelgov, J., & Meiran, N. (2013). How are automatic processes elicited by intended actions? *Frontiers in Psychology, 4,* 851. doi:10.3389/fpsyg.2013.00851

Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and poststimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 331–344. doi:10.1037/0096-1523.14.3.331

Guthrie, D., & Buchwald, J. S. (1991). Significance testing of difference potentials. *Psychophysiology, 28,* 240–244.

Hohlefeld, F. U., Nikulin, V. V., & Curio, G. (2011). Visual stimuli evoke rapid activation (120 ms) of sensorimotor cortex for overt but not for covert movements. *Brain Research, 1368,* 185–195. doi:10.1016/j.brainres.2010.10.035

Hollands, J. G., & Jarmasz, J. (2010). Revisiting confidence intervals for repeated measures designs. *Psychonomic Bulletin & Review, 17,* 135–138. doi:10.3758/PBR.17.1.135

Hommel, B. (2000). The prepared reflex: Automaticity and control in stimulus response translation. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 247–273). Cambridge, MA: MIT Press.

Huang, T. R., Hazy, T. E., Herd, S. A., & O'Reilly, R. C. (2013). Assembling old tricks for new tasks: A neural model of instructional learning and control. *Journal of Cognitive Neuroscience, 25,* 843–851.

Jarmasz, J., & Hollands, J. G. (2009). Confidence intervals in repeated-measures designs: The number of observations principle. *Canadian Journal of Experimental Psychology, 63,* 124–138.

Kopp, B., Mattler, U., Goertz, R., & Rist, F. (1996). N2, P3 and the lateralized readiness potential in a nogo task involving selective response priming. *Electroencephalography and Clinical Neurophysiology, 99,* 19–27.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility-a model and taxonomy. *Psychological Review, 97,* 253–270. doi:10.1037/0033-295X.97.2.253

Kranczioch, C., Mathews, S., Dean, P. J. A., & Sterr, A. (2009). On the equivalence of executed and imagined movements: Evidence from lateralized motor and nonmotor potentials. *Human Brain Mapping, 30,* 3275–3286.

Liefooghe, B., De Houwer, J., & Wenke, D. (2013). Instruction-based response activation depends on task preparation. *Psychonomic Bulletin & Review, 20,* 481–487.

Liefooghe, B., Wenke, D., & De Houwer, J. (2012). Instruction-based task-rule congruency effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38,* 1325–1335.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527. doi:10.1037/0033-295X.95.4.492

Logan, G. D. (1992). Attention and preattention in theories of automaticity. *American Journal of Psychology, 105,* 317–339.

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Meiran, N., & Cohen-Kdoshay, O. (2012). Working memory load but not multitasking eliminates the prepared reflex: Further evidence from the adapted flanker paradigm. *Acta Psychologica, 139,* 309–313. doi:10.1016/j.actpsy.2011.12.008

Meiran, N., Cole, M. W., & Braver, T. S. (2012). When planning results in loss of control: Intention-based reflexivity and working-memory. *Frontiers in Human Neuroscience, 6,* 104. doi:10.3389/fnhum.2012.00104

Meiran, N., Pereg, M., Kessler, Y., Cole, M. W., & Braver, T. S. (in press). The power of instructions: Proactive configuration of stimulus–response translation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. doi:10.1037/a0037190

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167–202. doi:10.1146/annurev.neuro.24.1.167

Moors, A., & De Houwer, J. (2006). Automaticity: A conceptual and theoretical analysis. *Psychological Bulletin, 132,* 297–326. doi:10.1037/0033-2909.132.2.297

Munzert, J., Lorey, B., & Zentgraf, K. (2009). Cognitive motor processes: The role of motor imagery in the study of motor representations. *Brain Research Reviews, 60,* 306–326.

Ramamoorthy, A., & Verguts, T. (2012). Word and deed: A computational model of instruction following. *Brain Research, 1439,* 54–65. doi:10.1016/j.brainres.2011.12.025

Rosenbloom, P. S., & Newell, A. (1986). The chunking of goal hierarchies: A generalized model of practice. In R. S. Michaliski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (Vol. 2, pp. 247–288). Los Altos, CA: Morgan Kaufmann.

Ruge, H., & Wolfensteller, U. (2010). Rapid formation of pragmatic rule representations in the human brain during instruction-based learning. *Cerebral Cortex, 20,* 1656–1667. doi:10.1093/cercor/bhp228

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime User's Guide. Pittsburgh: Psychology Software Tools, Inc.

Shahar, N., Teodorescu, A. R., Usher, M., Pereg, M., & Meiran, N. (in press). Selective influence of working memory load on exceptionally slow reaction times. *Journal of Experimental Psychology: General*. doi:10.1037/a0037190

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84,* 127–190. doi:10.1037/0033-295X.84.2.127

Smulders, F. T. Y., & Miller, J. O. (2012). The lateralized readiness potential. In S. J. Luck & E. S. Kappenman (Eds.), *Oxford handbook of event-related potential components* (pp. 209–230). New York, NY: Oxford University Press. doi:10.1093/oxfordhb/9780195374148.013.0115

Stocco, A., Lebiere, C., O'Reilly, R. C., & Anderson, J. R. (2012). Distinct contributions of the caudate nucleus, rostral prefrontal cortex, and parietal cortex to the execution of instructed tasks. *Cognitive, Affective, & Behavioral Neuroscience, 12,* 611–628. doi:10.3758/s13415-012-0117-7

Tzelgov, J. (1997). Automatic but conscious: That is how we act most of the time. In R. Wyer (Ed.), *Advances in social cognition* (Vol. 10, pp. 217–230). Mahwah, NJ: Erlbaum.

Verbruggen, F., & Logan, G. D. (2009). Automaticity of cognitive control: Goal priming in response-inhibition paradigms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 1381–1388. doi:10.1037/a0016645

Verbruggen, F., Logan, G. D., Liefooghe, B., & Vandierendonck, A. (2008). Short-term aftereffects of response inhibition: Repetition priming or between-trial control adjustments? *Journal of Experimental Psychology: Human Perception and Performance, 34,* 413–426. doi:10.1037/0096-1523.34.2.413

Wenke, D., Gaschler, R., & Nattkemper, D. (2007). Instruction-induced feature binding. *Psychological Research, 71,* 92–106. doi:10.1007/s00426-005-0038-y

Wenke, D., Gaschler, R., Nattkemper, D., & Frensch, P. A. (2009). Strategic influences on implementing instructions for future actions. *Psychological Research, 73,* 587–601. doi:10.1007/s00426-009-0239-x