Psychological Research
DOI 10.1007/s00426-016-0807-9

ORIGINAL ARTICLE

The role of executive control in the activation of manual affordances

Nikolay Dagaev[1] · **Yury Shtyrov**[1,2] · **Andriy Myachykov**[1,3]

Received: 11 March 2016 / Accepted: 15 September 2016

Abstract We investigated the role of executive control processes in the activation of manual affordances in two experiments combining stimulus–response compatibility (SRC) and dual-task paradigms. We registered an inverse SRC effect in the presence of a parallel backward-counting task in Experiment 1, and a cancellation of the SRC effect in Experiment 2 when a parallel Stroop-like task was used. We interpret our data as supporting a *self-inhibition* account of the affordance activation control. Accordingly, the role of executive processes is to prevent self-inhibition in supraliminal conditions: when cognitive resources are depleted by a parallel task, the self-inhibition mechanism becomes active and irrelevantly potentiated affordances are inhibited, leading to the emergence of an inverse SRC effect. In addition, the difference between data patterns observed in the two experiments suggests that the exact roles of the executive processes involved during the activation of affordances may differ. The results suggest a mechanism for action-related activation monitoring based on a flexible control over automatically potentiated actions. The paper discusses the proposed mechanism in detail and outlines further research directions.

Introduction

The concept of objects' *affordances* was initially introduced by Gibson (1979) in the context of ecological approaches to perception. Affordances are properties of the perceived objects that allow interaction with those objects and guide the corresponding actions. Contemporary theories (e.g. Borghi, 2012; Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013) view affordances as a special type of representations allowing perceptual-motor junctions. These representations are established gradually through learning and are activated automatically, typically in the bottom-up manner (Jax & Buxbaum, 2010; Tucker and Ellis, 1998; Vainio et al., 2014). Such junctions are formed between perceptual (most commonly, visual) patterns and typical motor responses; in other words, they are connections prescribed between the perceptual representation of an object and the typical action performed with it. These connections are believed to be robust and automatic as merely seeing an object leads to the activation of the associated motor program (e.g. *pen–write*; see Thill et al., 2013).

Substantial support for such automatic facilitation of action tendencies by affordances comes from the research using various versions of the so-called stimulus–response compatibility paradigm (SRC; Bub & Masson, 2010; Jax & Buxbaum, 2010; McBride, Sumner, & Husain, 2012; Tucker & Ellis, 1998, 2001). Typically, an SRC task requires participants to provide a category identification response (e.g. is this object a garage tool or a kitchen utensil?) to a visually presented manipulable object. A common finding is that the affordance associated with an object is automatically activated during object perception, which in turn affects the unrelated main task response, typically leading to its facilitation in matching conditions.

✉ Nikolay Dagaev
nikolaydagaev@gmail.com

[1] Centre for Cognition and Decision Making, National Research University Higher School of Economics, Moscow, Russian Federation

[2] Center of Functionally Integrative Neuroscience, Institute for Clinical Medicine, Aarhus University, Aarhus, Denmark

[3] Department of Psychology, Northumbria University, Newcastle-upon-Tyne, UK

For example, in one of the earliest demonstrations of automatic affordance activation (Tucker & Ellis, 1998), participants responded to household object (e.g. frying pan, knife, mug) orientation (upright vs. inverted) by pressing either a right or a left key. Crucially, the objects appeared with their graspable parts (i.e., handles) oriented rightward or leftward, thus matching or mismatching the unilateral hand response. Responses were faster in matching conditions, i.e., when the handle orientation and the lateral response were congruent even though the experimental task (vertical orientation identification) was orthogonal to this. Hence, apprehending a graspable object for an unrelated categorisation task appeared to automatically activate associated motor programs (*affordances*). Similar SRC effects do not only accompany activation of lateral affordances. For example, several studies (e.g. Bub & Masson, 2010; Tucker & Ellis, 2001) demonstrated that the grasp type can also be activated in a similar automatic fashion with data patterns resembling the lateral SRC effect. Automatic nature of affordances has subsequently been documented in numerous other studies (Buccino, Sato, Cattaneo, Rodà, & Riggio, 2009; Makris, Hadar, & Yarrow, 2011, 2013; Thill et al., 2013). For example, a transcranial magnetic stimulation study by Makris et al. (2011) found that modulations of muscle responses by the type of a primed grasp movement can be registered quite early (300–400 ms) after object presentation. Despite this putative automaticity, visual attention was still shown to play part in affordance activation. Although even peripherally presented graspable stimuli evoke affordances-related motor programs, this process is also suggested to involve attraction of attention (e.g. Makris et al., 2013).

More recent studies further investigated the nature of manipulation affordances including detailed analysis of their specific types (Binkofski & Buxbaum, 2012; Borghi, 2012), the role of attention in their potentiation (Kostov & Janyan, 2012; Makris et al., 2013; Myachykov, Ellis, Cangelosi, & Fischer, 2013), relation to other SRC effects (Symes, Ellis, & Tucker, 2005; Vainio et al., 2014), modulations of affordance effects by language (Borghi & Riggio, 2009; Myachykov et al., 2013), and neurophysiological correlates of affordances: P300 event-related potential (Proverbio, Adorni, & D'Aniello, 2011; Righi, Orlando, & Marzi, 2014) and event-related desynchronisation of the mu-rhythm in the motor cortex (Kourtis & Vingerhoets, 2015; Muthukumaraswamy, Johnson, & McNair, 2004; Proverbio, 2012). While many such studies support a largely automatic nature of affordance activation, the role of attention in these processes still remains debated. Some authors suggest that the activation of affordances occurs in a largely automatic fashion with little-to-none explicit allocation of attention and cognitive resources (e.g. Pappas and Mack, 2008; Vainio, Ellis, & Tucker, 2007). Others propose a substantial role for attention arguing for an attentional account of affordance effects (e.g. Anderson, Yamagishi, & Karavia, 2002; Handy, et al., 2003, 2005; Kostov and Janyan, 2012). Importantly, interactions with manipulable objects in real life (e.g. working with tools in a workshop) almost never occur in isolation from other cognitive processes, many of which are undoubtedly attention demanding and resource consuming. Therefore, a comprehensive theory of affordances needs to account for the role of executive processes in regulating action-related activations. Such an account would need to include mechanisms of inhibitory control over potentiated but irrelevant actions and, in particular, relations between these mechanisms and executive processes. In this context, it is important to mention the affordance competition hypothesis (Cisek, 2007; Cisek & Kalaska, 2010), which implies that multiple motor plans of potential actions are always activated in an automatic fashion leading to a competition between them. This model implies that the potential conflict is resolved by mutual inhibitory connections between alternative motor plans and mechanisms that express context- and goal-related preferences (implemented in prefrontal cortex and subcortical areas such as basal ganglia). However, this model does not specify the exact way executive processes perform such a bias. Moreover, the model is essentially dedicated to motor decision making, but it does not explicitly state how exactly irrelevant motor plans are prevented in situations that do not involve competition or when the potentiated motor plan is the "winner" itself, i.e. highly activated. A full account of the role of executive processes in the control of affordances-related action tendencies requires specifying a mechanism of dealing with irrelevant affordance itself, without reference to competitive alternatives. Such an account, however, is not available, not least due to lack of experimental data on executive control of affordance activation.

It is intuitively true that we do not indiscriminately perform all possible primed actions related to manipulable objects available for processing in a given perceptual context. In real life, one does not compulsively interact with every graspable object we encounter in the reachable space. However, in some neurological conditions (Lhermitte, 1983; Boccardi, Della Sala, Motto, & Spinnler, 2002; Shallice, Burgess, Schon, & Baxter, 1989), such compulsive and uncontrolled affordance activation can indeed take place. The phenomenon of utilisation behaviour describes a condition when patients with frontal lesions (particularly in prefrontal areas) perform irrelevant actions in spite of the absence of any obvious purpose, task, or intention. These unintended actions are predominantly triggered by manipulable objects (Lhermitte, 1983). Interestingly, the brain areas affected in patients with utilisation behaviour are also implicated in executive processes (e.g.

Koechlin, Ody, & Kouneiher, 2003). If it is indeed an executive control deficit in these patients that leads to misactivation of action tendencies by affordances, then a possible role for executive processes in affordance control could simply be an inhibitory one. In other words, a “theoretical candidate” for the inhibitory control mechanism is a system based on central executive processes (Baddeley, 1996)—the mechanisms supporting top-down, deliberate, conscious, endogenous, and goal-directed control of information flow and behaviour. Central executive processes are typically engaged when no ready and/or adequate solution is immediately available (Norman & Shallice, 1980). Often in this case, an automatically potentiated irrelevant response is available but inadequate. As a result, it needs to be inhibited to maintain proper goal-directed behaviour.

The linking hypothesis according to such an account is that, albeit affordance activation is generally a highly automated process, an effective executive control mechanism actively inhibits irrelevant object-related actions, and it is this mechanism that is impaired in utilisation behaviour. Based on this, it stands to reason that unavailability of central executive resources (e.g. as a result of a neurological condition, or because the resources are overloaded by a parallel task) should result in disinhibition of available but irrelevant actions (Lhermitte, 1983). Thus, if participants need to concentrate on a parallel task in a dual-task scenario with one of the tasks being an SRC affordance task, one can expect that disrupting central executive processes would lead to disinhibition of the affordances-related motor programs and result in a stronger facilitation pattern of an associated SRC effect.

We will refer to the above suggestion as the central inhibition hypothesis, implying that executive control processes directly inhibit irrelevant affordances. This, however, is not the only theoretical possibility for inhibitory affordance control. An alternative control mechanism could be that based on self-inhibition (Eimer & Schlaghecken, 2003)—an automatic process that prevents incidental motor activations. In their original study, Eimer & Schlaghecken (1998) used a masked priming paradigm: a brief (<20 ms) masked prime (arrow) was followed by a salient target stimulus that required a lateral response to the target identity—a left- or right-pointing arrow. Therefore, the primes in this study were congruent, incongruent, or neutral (outward-pointing arrows) with respect to the targets. When the stimulus onset asynchrony (SOA) between primes and targets varied between 90 and 190 ms, a negative compatibility effect (NCE) emerged: responses were slower and more error prone in congruent trials, while a reverse pattern was observed in the incongruent trials. Further studies demonstrated that the NCE emerged neither as a result of perceptual processing (Eimer, 1999, Experiment 1; Schlaghecken & Eimer, 2000, Experiment 2) nor because of a deep, semantic processing (Eimer, Schubö, & Schlaghecken, 2002). This pattern is typically explained via the notion of so-called self-inhibition (but see Sumner, 2007 for other possible accounts), i.e. a type of response inhibition implemented within the motor system itself with no explicit reference to goals or intentions. As such, it is distinct from the central executive processes hypothesised above, as self-inhibition implies reflexivity and autonomy and it can be triggered automatically without participant’s awareness (Eimer & Schlaghecken, 2003). Importantly, if a prime stimulus is presented in supraliminal conditions (i.e. is consciously perceived), the NCE disappears and may even inverse towards a typical positive SRC effect (Eimer & Schlaghecken, 2002). Furthermore, some studies indicate that the NCE has a threshold nature: when the perceptual strength of a prime is reduced, response inhibition is absent (Schlaghecken and Eimer, 2002); that is, the effect disappears and reverses toward a positive pattern if the motor-related activations are weak.

While self-inhibition is typically considered to be a distinct inhibitory control mechanism, it may be not completely impenetrable for top-down executive processes, and these two types of control can interact. For instance, Boy, Husain, & Sumner (2010) used a paradigm that combined both types of inhibitory processes and showed that subliminal self-inhibition (associated with the NCE in the masked priming paradigm) affects supraliminal central inhibition (associated with the flanker paradigm; Eriksen & Eriksen, 1974).

The above two strands of research—on affordances and on the NCE—converged in recent years (e.g. Makris & Yarrow, 2014; McBride et al., 2013; Vainio et al., 2014). McBride et al. (2013), for example, used an SRC task in conjunction with an NCE one (backward masked priming task) in a single-case study of a patient with the corticobasal syndrome accompanied by the alien hand behaviour. The latter refers to the neurological condition when a patient unintentionally performs hand movements, including grasping and manipulating objects, similar to the utilisation behaviour. The authors found an exaggerated positive compatibility effect in the object categorisation task alongside a reduced NCE effect in the masked priming task. They concluded that unintended grasping behaviour in patients with the alien hand syndrome may result from disruptions in the self-inhibition mechanism which, in turn, leads to the disinhibition of the affordances-related activations. These results suggest that mechanisms underlying affordance SRC effects and mechanisms of the NCE may have (some) common nature. Vainio et al. (2014) attempted to adapt the NCE paradigm in an affordance experiment and demonstrated that, in the compatible condition, a subliminal presentation of a manipulable prime (a mug) before the target stimulus inhibited responses. They, however, rejected the self-inhibition explanation since no typical activation-followed-by-inhibition pattern was observed in the lateralised readiness potentials while only an inhibition effect was found. Note that the authors used an object picture (a mug) as the subliminal prime presented for 25 ms. This detail limits the theoretical generalisation scope, since most of the studies performed to date used much longer stimulus presentation durations leading to explicit object presentation. Recently, Kostov & Janyan (2015) registered an inverse affordance SRC pattern similar to the NCE using exogenous attention-capturing cues (they even registered such a pattern in the control condition). The authors interpreted this inverse pattern as resulting from the inhibition of exogenous attention and concluded that a top-down control mechanism gauging intentional and goal-directed central executive processes must be involved during lateral affordance activation.

In sum, the field appears to have diverging evidence on the subject of affordance activation control, particularly on the involvement of executive processes in it. To address this, we have performed two experiments that directly investigated the role of executive processes in activation of lateral affordances. We contrasted two alternative accounts of inhibitory control of affordances: central inhibition and self-inhibition. Importantly, these two accounts differ with respect to the role played by executive processes: a direct inhibition (central inhibition account) or a prevention of self-inhibition (self-inhibition account) of irrelevantly activated affordances. In both experiments, we contrasted participants' performance between control conditions (a classical SRC affordance task; Tucker & Ellis, 1998) and a demanding dual-task scenario. The latter dual-task scenario involved (1) the SRC task used in the control condition accompanied by (2) a parallel interference task.

Under the central inhibition account, we expected to observe a disinhibition of potentiated affordances similar to the pattern observed in patients with the utilisation behaviour. Since both tasks need to be performed simultaneously, an interference task was expected to overload executive processes (e.g. Szameitat, Schubert, Müller, & Von Cramon, 2002) leading to the amplification of the associated SRC effect. In other words, based on the evidence regarding the role for central mechanisms in the control of automatically activated motor programs (Lhermitte, 1983; Boccardi et al., 2002; Shallice et al., 1989), we hypothesised that disturbing the usual functioning of executive processes by means of a parallel interference task would amplify the typically documented difference between compatible and incompatible conditions.

According to the self-inhibition account (cf. Eimer and Schlaghecken, 2003), a different pattern was expected: an inversion of the SRC effect in the presence of the parallel task in the form resembling the NCE. We propose that in supraliminal conditions of stimuli presentation, which are common in affordances studies, the self-inhibition mechanism might not be triggered because more efficient central control is available. Thus, in contrast to the central inhibition account, inhibitory control over irrelevant affordances is implemented by a peripheral, unconscious, and automatic mechanism of self-inhibition. Importantly, executive processes play the opposite role here: they *prevent* self-inhibition and allow some level of activation for irrelevant affordances. While this particular type of interaction between executive processes and self-inhibition was not suggested in earlier studies and is proposed here for the first time, it appears plausible due to the known mutual influences between these two (Boy et al., 2010). If this is indeed the role of executive processes in the control of affordances, then making the central mechanisms partially unavailable using an interference task should lead to the involvement of the self-inhibition mechanism, as it is the case in subliminal settings when the executive processes are unavailable by default.

Experiment 1

Dual-task protocols are considered as rather demanding for the executive control mechanisms (e.g. Baddeley, 1996). To maximise the possible effects on affordance activations, we chose an interference task in Experiment 1 that would require the involvement of executive functions even in the absence of any other parallel processes, the *backward-counting* task (Peterson and Peterson, 1959). Our choice was motivated by two reasons. First, this task requires a continuous performance within a trial. Second, the experimental modalities for the primary SRC task and for the backward-counting task are non-overlapping: a combination of visual presentation with manual response in the former and of auditory presentation and vocal response—in the latter. These two criteria provided us with an opportunity to match the timings in the two tasks and to minimise irrelevant modality-specific factors.

Our goal in Experiment 1 was to investigate the role of the executive processes load, operationalised via the use of a backward-counting task, on the emergence of a lateral affordance SRC effect. Based on the *central inhibition* account, we hypothesised that the presence of the simultaneous interference task should amplify the differences in reaction times and possibly also in accuracies between compatible and incompatible trials, thus increasing the general compatibility effect in comparison with the control condition using the SRC task alone. Based on the self-inhibition account, reaction times and possibly error rates should be higher in compatible trials compared to incompatible ones in the presence of the interference task, thus reflecting the inversion of the compatibility effect. In addition, we expected the control condition to replicate the classical compatibility pattern as reviewed above.

Methods

Participants and design

Twenty-four right-handed native Russian speakers (age range 19–28, $M = 22.92$, SD = 2.41; 17 females) volunteered to participate in the experiment. Participants in both experiments were treated in accordance with the ethical principles of the Helsinki Declaration. Ethics permission for the studies was granted by the HSE Research Ethics Committee.

Two experimental factors were independently manipulated in Experiment 1: (1) Stimulus–Response Compatibility (Compatible/Incompatible) and (2) Task (Interference/Control). Therefore, we implemented a 2 × 2 within-participant design. The main dependent variable was task-related reaction time (RT); in addition, response accuracies were also analysed.

Materials

The visual stimuli were different orientation variants of nine colour images of graspable household items (three cups, two teapots, gravy boat, watering can, colander, coffee can). As manipulation affordance effects are highly sensitive to whether visual stimuli are realistic or not (e.g. photographs vs. line drawings; Pappas, 2014; see also: Fischer & Dahl, 2007; Symes, Ellis, & Tucker, 2007), we chose to derive our stimulus set from the database of the photographs of manipulable objects. The photographs were taken from Amsterdam Library of Object Images (ALOI; Geusebroek, Burghouts, & Smeulders, 2005). The size of each picture was 1024 × 768 pixels. Each object had the horizontal handle rotation of 45 degrees relative to the observer's viewpoint. All the stimuli varied systematically in handle direction (left/right) and vertical orientation (upright/inverted). As a result, each object appeared in four possible variations through the experiment. The resulting set of 36 stimuli was presented twice: once in the interference and once in the control task, which will be described below.

The auditory stimuli for the backward-counting task were digital audio recordings (32 bit, sampled at 22,050 Hz) of Russian number names in female voice. The numbers ranged between 20 and 60. The duration of recordings varied between 800 and 1000 ms. Different auditory number stimuli were randomly assigned to the individual Interference trials.

Procedure

Participants were positioned approximately 60 cm in front of the monitor and responded to the SRC task by means of keyboard presses. Auditory stimuli for the backward-counting task were presented binaurally via headphones. The experiment was implemented in PsychoPy v1.82.01 (Peirce, 2007).

Before each experimental session, participants were instructed to respond as fast and as accurate as possible and to consider both tasks as equally important. The experiment began with 10 practice trials (different from the main experimental ones), followed by the 144 target trials. 72 of these trials included the Interference task and the other 72 were Control trials, the order of Interference and Control trials being individually randomised for each participant. Each trial started with a centrally presented fixation cross (60 × 60 pixels). After 250 ms, in the Interference task trial (see Fig. 1), participants heard a number (random between 20 and 60), which they were instructed to use as a starting point for a mental arithmetic task—subtracting in steps of three every time they hear an auditory signal (450-Hz tone, 200 ms in duration). After each tone, they had to verbally report the result of the subtraction. The interval between successive tones was 1900 ms. The number of tones varied between two and four assigned randomly on each trial, so the exact number of subtractions to be done in a given trial was unknown to participants. During the task, the target object was presented for the maximum duration of 2000 ms simultaneously with the second or the third tone and with an onset-to-onset (tone-to-image) delay of 100 ms. Participants judged whether the object was presented upright or inverted, by means of a right- or a left-hand key press (right CTRL vs. left CTRL; response mapping was counterbalanced across participants). The object disappeared immediately after the response but no later than after a 2000-ms time-out. The response did not terminate the full trial as in some trials more subtractions had to be performed after the SRC task completed. Following this, participants were only provided with a negative feedback in the case of an erroneous response ("Wrong") or in the absence of any response ("Too slow"). Participants proceeded to the next trial by pressing the spacebar.

The Control trials were identical to the Interference trials in their events' chronometry, the feedback, and the next trial initiation for the SRC task but did not include the parallel backward-counting task and auditory signals. To provide a form of post hoc control over the backward-counting task performance, in nine catch Interference trials participants had to indicate the final result of subtraction on the scale (10–70) presented before the feedback.

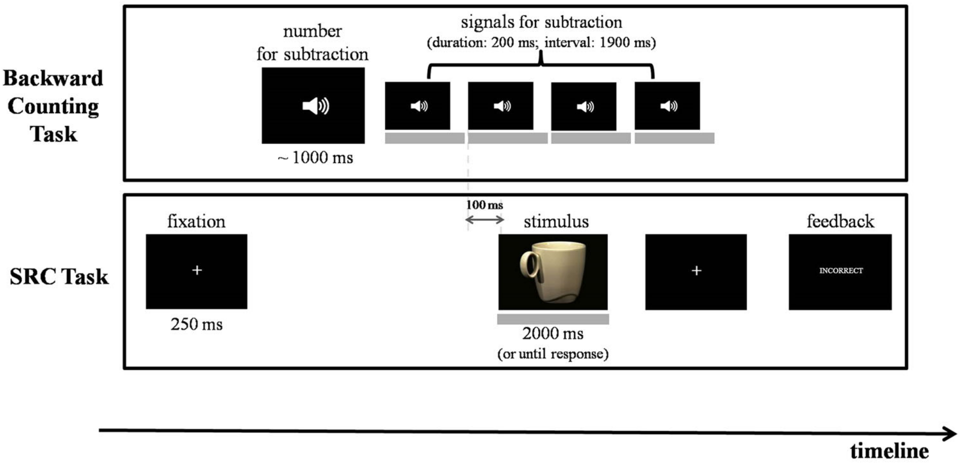

Fig. 1 Design of an Interference trial in Experiment 1. Backward-counting and stimulus–response compatibility (SRC) tasks are in separate *boxes*. Time windows for responses in both tasks (verbal in backward-counting and manual in SRC) are indicated by *grey rectangles*

Results

RTs from incorrect trials were excluded from the analysis. The data from three participants were excluded from the subsequent analysis because of poor compliance with experimental instructions that led to over 40 % error rate in the SRC task. For each remaining participant, RTs outside the three standard deviations range around the participant's conditional mean were eliminated (about 2 % of the data). Performance on the catch trials was no less than five out of nine correct answers for every participant ($M = 6.905$, $SD = 1.179$). A repeated measures ANOVA was performed on the RT data pulled from 21 participants with the following factors: Stimulus–Response Compatibility (Compatible vs Incompatible) and Task (Interference vs Control). Mean RTs in each combination of the factors are presented in Table 1.

Below, only statistically reliable results (thresholded at $p = 0.05$) are reported. The ANOVA indicated a reliable main effect of Task ($F(1, 20) = 43.589$, $p < 0.001$, $\eta_p^2 = 0.685$): performance in Interference trials was slower than in Control trials. More importantly, in line with our experimental predictions, there was a reliable Compatibility × Task interaction [$F(1, 20) = 10.589$, $p = 0.004$, $\eta_p^2 = 0.346$; see Table 1; Fig. 2]. This interaction was followed up with planned paired-samples *t* tests (corrected for False Discovery Rate (FDR) according to Benjamini & Hochberg, 1995) which indicated that it was due to reliably faster RTs in the Control condition on compatible trials than on incompatible ones [$t(20) = 2.772$, $p = 0.012$, $\eta^2 = 0.278$] while the opposite effect was observed in the Interference condition, where compatible trials led to reliably slower RTs than incompatible ones [$t(20) = -2.331$, $p = 0.03$, $\eta^2 = 0.214$]. Thus, while the Control task showed a typical compatibility affordance effect, its inversion was found in the presence of the interfering backward-counting task.

Since RTs in the Interference condition are higher than RTs in the Control condition, one might suggest that the observed inverse pattern is not due to the interference itself but rather to the relatively inflated response latencies: it

Table 1 Mean reaction times (in milliseconds) and accuracies in the Experiment 1; standard errors are in parentheses

	Stimulus–response compatibility		
	Compatible	Incompatible	Difference
Task			
Interference			
RT	999 (32)	958 (33)	−41
Accuracy	0.87 (0.019)	0.88 (0.013)	0.01
Control			
RT	702 (27)	739 (29)	37
Accuracy	0.95 (0.009)	0.91 (0.013)	−0.04

The differences were computed by subtracting Compatible means from the corresponding Incompatible means

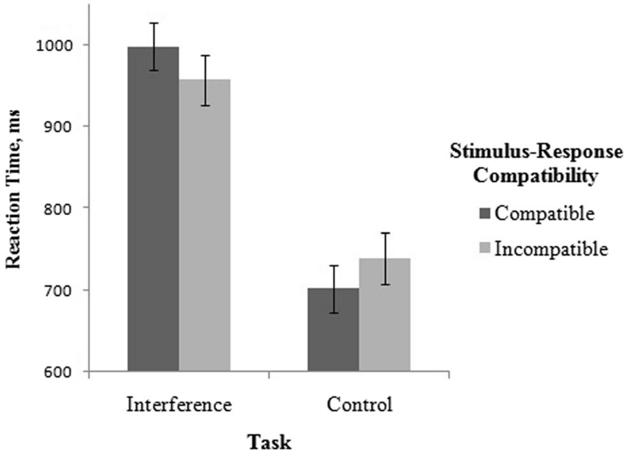

Fig. 2 Mean reaction times (with standard errors) in Experiment 1. Stimulus–Response Compatibility by Task interaction. *Error bars* represent standard errors

may be possible that the SRC effect has temporal dynamics such that it reduces and perhaps reverses with increasing response latency. Indeed, if the explanation in terms of executive processes load by the backward-counting task accounts for the inverse SRC effect, this effect must hold for the latencies comparable with latencies of the Control condition. To test this, we split ordered RT data into four equal bins, separately for compatible and incompatible trials in both Interference and Control conditions, and analysed resulted RT distributions. Figure 3 depicts the SRC effect sizes (RT difference between incompatible and compatible trials) for every bin in the Control and Interference conditions. Performance in compatible trials was faster than in incompatible ones for each bin in the Control condition, with this difference apparently increasing as a function of the bin order; however, Compatibility x Bin interaction was not significant. For the Control condition, the main effects of Compatibility [$F(1, 20) = 8.200$, $p = 0.01$, $\eta^2_p = 0.291$] and Bin [$F(3, 60) = 108.125$, $p < 0.001$, $\eta^2_p = 0.844$] were significant. At the same time, performance in compatible trials was slower than in incompatible ones for each bin in the Interference condition (Compatibility × Bin interaction was not significant). For the Interference condition, the main effects of Compatibility [$F(1, 20) = 7.259$, $p = 0.014$, $\eta^2_p = 0.266$] and Bin [$F(3, 60) = 112.238$, $p < 0.001$, $\eta^2_p = 0.849$] were also significant.

With repeated measures ANOVA, we further analysed first (the fastest) compatible ($M = 743$ ms, SE = 27 ms) and incompatible ($M = 699$ ms, SE = 26 ms) bins from the Interference condition and fourth (the slowest) compatible ($M = 904$ ms, SE = 45 ms) and incompatible ($M = 974$ ms, SE = 38 ms) bins from the Control condition. As for the whole dataset, we found a significant Compatibility x Task interaction [$F(1, 20) = 11.494$, $p = 0.003$, $\eta^2_p = 0.365$]. This interaction was followed by planned paired-samples *t* tests which indicated that it was due to significantly faster RTs in the Control condition on compatible trials than on incompatible ones [$t(20) = 2.403$, $p = 0.026$, $\eta^2 = 0.224$] and to significantly slower RTs in the Interference condition on compatible trials than on incompatible ones [$t(20) = -2.353$, $p = 0.029$, $\eta^2 = 0.217$]. Thus, the compatibility effect in the Control condition's slowest bins was not just larger than the compatibility effect in the fastest bins of the Interference condition but the latter had the opposite direction. In other words, the classical SRC effect and the inverse SRC effect were present even at RT levels that are comparable in the Interference and Control conditions supporting our explanation in terms of executive processes load by the backward-counting task.

Splitting the data according to the upright and inverted object presentation revealed equal SRC effect sizes for upright stimuli (36 ms) and inverted ones (39 ms) and equal inverted SRC effect sizes for upright (47 ms) and for inverted (36 ms): after adding a vertical orientation as an additional factor to repeated measures ANOVA, no significant three-way interaction was found, $F(1, 21) < 1$.

Analysis of accuracies (see Table 1) further corroborated the main RT pattern: higher accuracies for the Control trials than for the Interference trials were observed [$F(1, 20) = 20.833$, $p < 0.001$, $\eta^2_p = 0.51$] as well as the reliable interaction between the factors [$F(1, 20) = 5.316$, $p = 0.032$, $\eta^2_p = 0.21$].

Discussion

Experiment 1 investigated the effect of a parallel backward-counting task on the emergence and the pattern of a lateral affordance SRC effect (Tucker & Ellis, 1998). First, we replicated the well-documented SRC effect in the Control condition where a typical congruency pattern was observed. This finding is in line with previous research, and, importantly, confirms the validity of our experimental

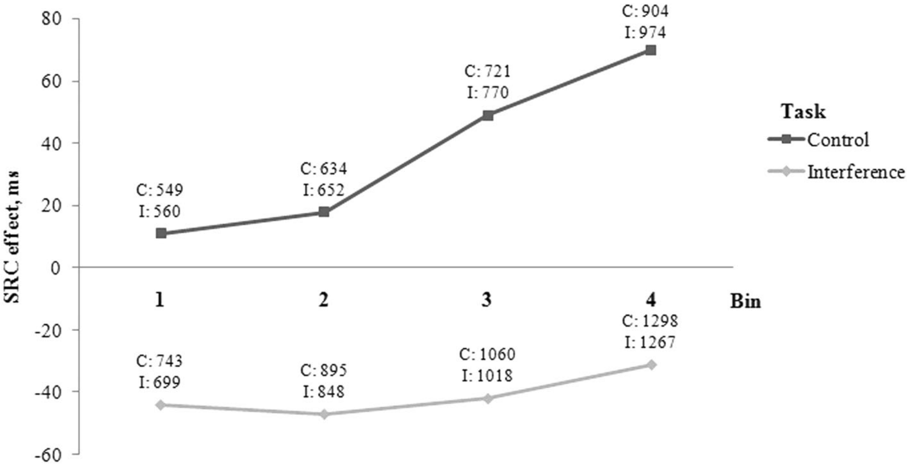

Fig. 3 Mean SRC effect size (difference between mean incompatible and compatible reaction times) as a function of bin for the Interference and Control conditions in Experiment 1. Each point is accompanied by corresponding mean reaction times (in milliseconds) for compatible and incompatible trials (denoted as "C" and "I", respectively)

design. Second, we registered a reliable interaction between the task (Control vs. Interference condition) and the SRC. Increasing the cognitive load by a parallel backward-counting task led to the inversion of the SRC pattern observed in the control condition: slower responses in compatible than in incompatible trials. We interpret this pattern as similar to the NCE effect discussed above (Eimer & Schlaghecken, 1998), hence supporting the self-inhibition account of the current result. This novel finding warrants a brief discussion before we proceed to Experiment 2.

Unlike the previous NCE reports, the inverse SRC effect observed here was obtained using cross-modal task interference in an overt unmasked task, and not in a masked priming paradigm. Note that it was previously reported that the NCE disappears in supraliminal conditions Schlaghecken & Eimer, 2002) and that it has a thresholded nature (Schlaghecken & Eimer, 2002). It is, therefore, possible that no self-inhibition regularly occurs in supraliminal conditions due to the availability of the central control mechanisms that monitor level of action-related activation and increase the threshold for self-inhibition. Under conditions when a stimulus is consciously perceived (e.g. control condition in our studies), a typical SRC pattern is observed since mild automatic affordance activation is not inhibited, facilitating a compatible response. Increasing cognitive load by adding a parallel task makes consistent top-down monitoring difficult, leading to the drop of the self-inhibition threshold. As a result, the same level of activation becomes sufficient to elicit the self-inhibition pattern.

These findings differ from those of Kostov and Janyan (2015, see Introduction) in a number of ways. First, our experiment involved an explicitly demanding parallel backward-counting task, which was different from the primary task in both presentation and response modalities. Second, we registered a typical SRC pattern in the control condition in contrast to Experiment 3 of Kostov and Janyan. These two crucial differences make a visual attention account inapplicable to current findings. Instead, we propose a lack of a central control that is independent of presentation modality.

The inversion pattern observed here has an overt similarity with results typical for the logical recoding account (Hedge and Marsh, 1975). According to this theory, in a congruent mapping of a task-relevant feature (e.g. green stimulus—green response key) participants employ a corresponding identity rule, while in an incongruent mapping of the same feature (e.g. green stimulus—red response key) they employ a reverse rule that is inadvertently applied to the irrelevant dimension (e.g. location). A typical finding is that the Simon effect (another stimulus–response compatibility effect where irrelevant spatial location of a stimulus facilitates responses in a colour identification task; Simon, 1969) reverses in the incongruent colour mapping between stimulus and response key. However, the present paradigm is very different from those used in the studies of the logical recoding. Moreover, some details of the present experimental procedure make direct application of the logical recoding account untenable. First, logical recording account was proposed with respect to the Simon effect, not any of affordance effects. While there is some debate on the relations and similarities between the two, there is evidence suggesting that the lateral affordance SRC effect is based on different mechanisms (e.g. Wilf, Holmes, Schwartz, & Makin, 2012). Second, stimuli for the SRC and the backward-counting tasks in our study were different (even in modality) and there was no feature shared between the two tasks—that is, there was no feature to be mapped between stimuli in one task and responses in the other. Third, the backward-counting task itself does not require any incongruent mapping similar to the typical stimulus–response mapping used in studies of the logical recoding (e.g. Hedge & Marsh, 1975).

Overall, the results of Experiment 1 are in line with a typical NCE pattern (Eimer & Schlaghecken, 2003) prompting an account based on monitoring of action-related activation. However, it is in principle still possible that this pattern is limited to the specific interference task employed and, therefore, would not generalise to other interference scenarios. In other words, given a diversity of executive processes (e.g. Miyake et al., 2000), it is possible that the specific mechanisms of monitoring are limited just to a subset of these. Moreover, the same logic suggests that, under different conditions, a central inhibition account may still hold: it is in principle possible that the hypothesis about the amplification of the SRC effect was not supported in Experiment 1 simply because of the irrelevance of the processes that were loaded. Experiment 2 was conducted to test these possibilities.

Experiment 2

The aim of the Experiment 2 was twofold: (1) to further test the generality of the inverse SRC effect observed in Experiment 1 and (2) to test the central inhibition hypothesis when a theoretically relevant executive process is loaded. To satisfy both criteria, we invoked a notion of "active inhibition" (Miyake et al., 2000), which relates to inhibiting task-irrelevant responses to avoid potential distractor effects on performance and to preserve the goal-directed behaviour. From the central inhibition account, it is the most relevant candidate (among executive process) for the inhibitory mechanism acting on irrelevant affordances. With respect to the self-inhibition perspective, backward-counting task may not necessarily involve this executive process; thus, using a task that involves active inhibition is important to test the generality of the inverse SRC effect. One of the most conventional paradigms used to investigate the active inhibition process is the Stroop task (Stroop, 1935). With the purpose to keep both presentation and response modalities in the primary and interference tasks non-overlapping, we used the auditory version of the Stroop task (Morgan & Brandt, 1989; Roberts & Hall, 2008), in which participants are presented with auditory words with the task to indicate the pitch of a voice as high or low. The word's meaning can be congruent (e.g. *HIGH* pronounced in high pitch) or incongruent (*HIGH* pronounced in low pitch) with the pitch. The latter condition implies a conflict and thus, for correct behaviour, irrelevant automatic responses must be inhibited.

With respect to the central inhibition account, our hypothesis for Experiment 2 was similar to that of Experiment 1: in the presence of the interference task that loads a corresponding executive process, the SRC effect should increase. The difference between compatible and incompatible trials in the Interference condition would be larger than this difference in the Control condition. More precisely, this disinhibition pattern is expected to be found in the Incongruent condition (in contrast to the Control one), since it requires inhibition of irrelevant responses, thus being more demanding for the executive process of interest (Stroop, 1935).

Methods

Participants and design

Twenty-five right-handed native Russian speakers (age range 18–25, $M = 20.68$, $\mathrm{SD} = 2.41$; 16 females) volunteered to participate in the experiment. There were two independently manipulated factors: (1) Stimulus–Response Compatibility (Compatible/Incompatible) and (2) Stroop task (congruent/incongruent/neutral/control). The two factors resulted in the 2 × 4 within-participants design. As in Experiment 1, the main dependent variable of interest was reaction time (RT) but accuracies were also analysed.

Materials

The stimuli for the SRC task were the same as in Experiment 1. The only difference was that the set of 36 images was presented only once at each level of Stroop task to reduce the number of repeated presentations of the same object. The stimuli for the auditory Stroop task were audio recordings (32 bit, 22,050 Hz sampling rate) of Russian adjectives pronounced in female voice. The critical words were *HIGH* (высокий, [vɨsˈokʲɪj]) and *LOW* (низкий, [nʲˈiskʲɪj]) for Congruent and Incongruent trials, and *RED* (красный, [krˈasnɨj]) and *BLACK* (черный, [t͡ɕˈornɨj]) for Neutral trials. Each of these words had two variations: pronounced in high pitch and in low pitch. High- (260 Hz) and low-pitch (146 Hz) versions were artificially derived from the same recordings by adjusting the pitch using professional sound-editing software (Audacity 2.1; audacityteam.org). Before the actual experiment, we asked ten subjects to listen to the recordings and to identify the words and their respective pitches; they correctly recognised all of these with 100 % accuracy. The duration of recordings varied between 800 and 900 ms.

Procedure

The procedure was similar to Experiment 1 except for the parallel task in Interference trials. On each trial (see Fig. 4), participants heard an adjective via stereo headphones; they had to verbally report the pitch of the voice. At the same time, after a 100 ms onset-to-onset delay, an image for the SRC task was presented. In nine catch Interference trials, participants had to indicate the pitch height on the scale (with two options: "high" and "low") presented before the feedback. The total number of trials was 144, 36 per level of the Interference task (including the Control condition). Twelve practice trials were administered in the beginning of the experiment.

Results

RTs from incorrect trials were excluded from the analysis. Data from two participants were excluded from the subsequent analysis because of poor compliance and resulting low accuracy on the SRC task (over 45 % errors). For each participant, RTs outside the three standard deviations range around the participant's mean were eliminated (about 2 % of data). The performance of the auditory Stroop task on the catch trials was no less than six out of nine correct answers for every participant ($M = 6.783$, $\mathrm{SD} = 0.998$).

First, repeated measures ANOVA was performed on all the RT data pulled from 23 participants with the two independent factors: Stimulus–Response Compatibility (Compatible vs Incompatible) and Stroop condition (Congruent vs Incongruent vs Neutral vs Control). Mean RTs in each combination of these factors are presented in the Table 2.

The analysis revealed a main effect of SRC [$F(1, 22) = 12.204$, $p = 0.002$, $\eta_{\mathrm{p}}^2 = 0.357$]: RTs on Compatible trials were faster than RTs on Incompatible trials. The effect of Stroop task was also reliable [$F(3, 66) = 71.002$, $p < 0.001$, $\eta_{\mathrm{p}}^2 = 0.763$]. The analysis did not reveal significant interaction between SRC and Stroop task.

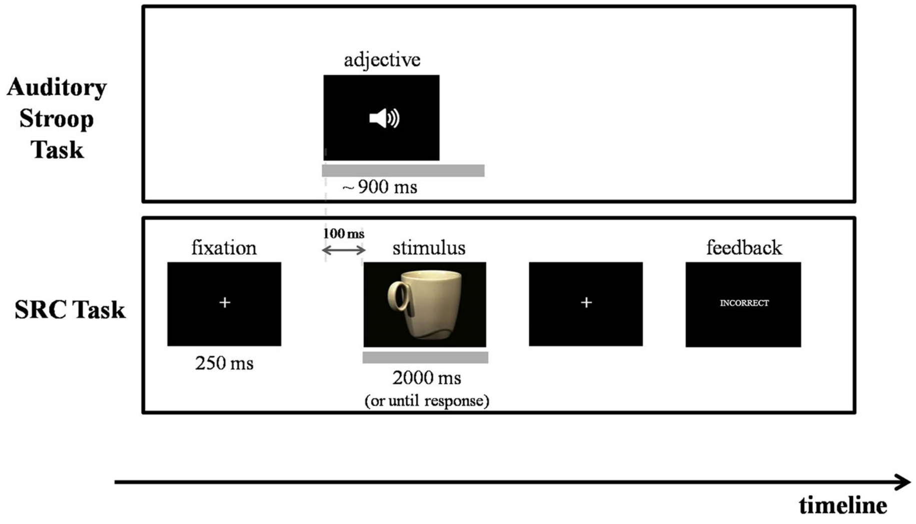

Fig. 4 Design of a Stroop trial in Experiment 2. Auditory Stroop and Stimulus–Response Compatibility (SRC) tasks are in separate *boxes*. Time windows for responses in both tasks (verbal in auditory Stroop and manual in SRC) are indicated by *grey rectangles*

Table 2 Mean reaction times (in milliseconds) and accuracies in the Experiment 2; standard errors are in parentheses. The differences were computed by subtracting Compatible means from the corresponding Incompatible means

	Stimulus–response compatibility		
	Compatible	Incompatible	Difference
Stroop condition			
Incongruent			
RT	1056 (24)	1061 (20)	5
Accuracy	0.74 (0.014)	0.72 (0.015)	−0.02
Congruent			
RT	960 (26)	979 (23)	19
Accuracy	0.78 (0.013)	0.76 (0.023)	−0.02
Neutral			
RT	1011 (21)	1048 (18)	37
Accuracy	0.82 (0.021)	0.77 (0.019)	−0.05
Control			
RT	830 (16)	885 (15)	55
Accuracy	0.86 (0.017)	0.81 (0.021)	−0.05

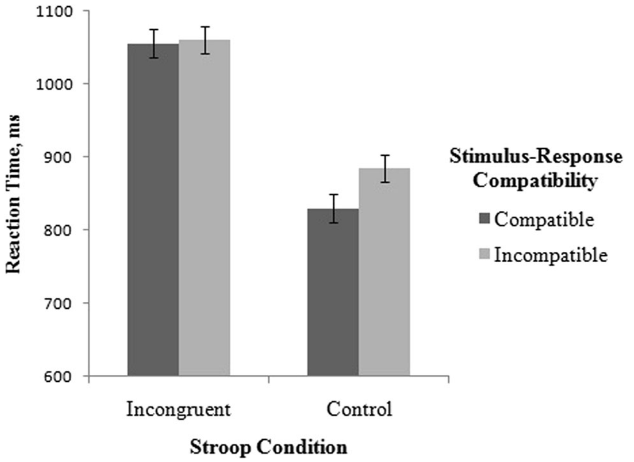

Fig. 5 Mean reaction times (with standard errors) in Experiment 2. Stimulus–Response Compatibility by Stroop condition (Incongruent and Control) interaction. *Error bars* represent standard errors

In line with our a priori set effects of interest, a repeated measures ANOVA was applied to the same data, using only two levels of Stroop task: Incongruent and Control. Again, a main effect of SRC was reliable [$F(1, 22) = 7.772$, $p = 0.011$, $\eta_p^2 = 0.261$] with faster RTs on Compatible trials. Stroop task also reliably affected RTs [$F(1, 22) = 105.548$, $p < 0.001$, $\eta_p^2 = 0.828$] with the fastest RTs on Control trials. The interaction between the two factors was found to be significant as well [$F(1, 22) = 4.856$, $p = 0.038$, $\eta_p^2 = 0.181$; see Fig. 5]. Planned paired-samples *t* tests (FDR-corrected; Benjamini & Hochberg, 1995) revealed that RTs on Compatible trials were significantly faster than RTs on Incompatible trials only in Control level of the Stroop task [$t(22) = 3.157$, $p = 0.005$, $\eta^2 = 0.312$].

Splitting the data according to upright and inverted objects revealed a similar SRC effect size for upright stimuli (61 ms) and inverted ones (54 ms) in the Control condition and no SRC effect for upright stimuli (−10 ms) and inverted ones (16 ms) in the Incongruent condition: after adding a vertical orientation as an additional factor to repeated measures ANOVA, no significant three-way interaction was found, $F(1, 23) < 1$.

Additional analysis of accuracies (see Table 2) revealed a complementary pattern: the reliable main effect of SRC [$F(1, 22) = 4.766$, $p = 0.04$, $\eta_p^2 = 0.178$] and the reliable main effect of Stroop task [$F(1, 22) = 13.189$, $p < 0.001$, $\eta_p^2 = 0.375$].

Discussion

Experiment 2 revealed neither the pattern directly predicted by the central inhibition account, nor the one based on the self-inhibition account. Rather than enlarging or inverting the SRC effect, the Incongruent condition of the Stroop task completely "eliminated" it. The analysis has shown that the difference between incompatible and compatible trials gradually decreased with the level of the Stroop task in the following order: Control > Neutral > Congruent > Incongruent. Importantly, Stroop level complexity (according to RTs and error rates) increases in the order: Control < Congruent < Neutral < Incongruent, and thus the overall difficulty in terms of the SRC task was higher in the Neutral rather than in the Congruent condition. Because of this, the gradual disappearance of the affordance SRC effect cannot be explained simply by an increase in the Stroop task complexity. Instead, to explain this pattern, an additional process must be involved. As the most likely explanation, we suggest that both Congruent and Incongruent Stroop conditions increase demands on attention: Since an auditory stimulus on each of those trials was similar to the response options, extra attentional effort was required to clarify whether this stimulus was consistent with a response actually implied by the pitch of this stimulus. According to this scenario, this increase is a unifying property of both Congruent and Incongruent trials in comparison to both Neutral and Control trials, and it leads to a reduced processing of the visual stimulus in the SRC task. Indeed, it is known that some level of attention is needed for the affordance activation (e.g. Makris et al., 2013; Myachykov et al., 2013; Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010). The disappearance of the SRC effect observed in Experiment 2 is similar to some previous studies that used tasks not requiring sufficiently deep stimulus processing (e.g. Tipper, Paul, & Hayes, 2006). Interestingly, in these studies the overall task performance both in the conditions where the effect was absent and where it was present was approximately the same. In other words, different levels of processing depth did not lead to the difference in performance on the main task but only to the categorical presence or absence of the compatibility effect; that is, while participants' performance in the Congruent condition of Experiment 2 (970 ms) was roughly the same as performance in the Interference condition of Experiment 1 (979 ms), it does not necessarily mean that the levels of processing were comparable as well. Thus, in our case, it is possible that the demands posed by the simultaneously performed Stroop task prevented the processing of manipulable objects to a level sufficient to activate their respective action-related affordances.

Along with that, the pattern obtained in Experiment 2 is different from the pattern found in Experiment 1 indicating that the inverse SRC effect observed in Experiment 1 may be limited to the use of a backward-counting task and, as such, is not easily generalisable. Overall, Experiment 2 results imply that a minimal level of processing is required for the affordance SRC effects to emerge.

General discussion

In two experiments, we aimed at investigating the role of executive processes in the control of lateral affordances. Both studies used a dual-task paradigm: a lateral affordance SRC task (Tucker & Ellis, 1998) was accompanied by a parallel interference task—a backward-counting task in Experiment 1 and an auditory Stroop task in Experiment 2. We entertained two contrasting theoretical accounts, both predicting a specific modulation of the classically observed affordance SRC pattern by different types of interference resulting from the two different parallel tasks used. According to the central inhibition account, executive processes should inhibit irrelevant affordances potentiated by objects when one does not intend to use them. The necessity to perform a parallel task should, therefore, lead to the executive system overload and result in disinhibition of the object's affordances leading to the registration of an amplified SRC pattern: more facilitation in the compatible condition and more interference in the incompatible one. The alternative self-inhibition account suggests that executive functions provide a kind of active monitoring of motor activations (rather than active inhibition of these) which raises the threshold for the self-inhibition, thus resulting in a response facilitation for complementary actions. Under this account, the use of a parallel interference task would release self-inhibition and thus elicit an *inverse* SRC effect similar to the previously reported NCE pattern.

First, the classical affordance SRC effect was replicated in control conditions in both experiments, validating our design. Second, when the backward-counting task was used in Experiment 1, we observed an inverted SRC pattern similar to the one found in the NCE studies (Eimer & Schlaghecken, 2003). Third, the use of an auditory Stroop task in Experiment 2 eliminated the affordance SRC effect altogether. Below we briefly discuss these main results against the hypotheses we set forward for our two studies.

Activation monitoring and self-inhibition

Ultimately, our results demonstrate different influence on the affordance SRC effect by the two types of interference we used in Experiments 1 and 2. Because the inverse SRC effect in Experiment 1 was similar to the

NCE pattern, we propose a common mechanism. Importantly, a typical NCE pattern is known to emerge in subliminal conditions and to disappear when the stimulus is perceived consciously. In contrast to this, here, a similar pattern was obtained with *supraliminal* stimulus presentation. To account for the inversion of the SRC effect in Experiment 1, we propose a monitoring role for the central control: a process that monitors the strength of an activated action representation and prevents self-inhibition (because more flexible control is available). This is done by means of raising its triggering threshold, and thus stronger activation is needed to initiate self-inhibition. Under regular conditions, this monitoring process is constantly available, and the activations primed by familiar graspable objects do not trigger self-inhibition. In this case, classical SRC patterns are observed (Bub & Masson, 2010; Eimer & Schlaghecken, 2003; McBride et al., 2012; Tucker & Ellis, 1998). When this monitoring mechanism is unavailable, the threshold for self-inhibition drops and a negative SRC pattern, similar to the NCE, emerges. Since the common condition for the emergence of the NCE implies subliminal prime presentation (Eimer & Schlaghecken, 1998), such a monitoring process is unavailable in the standard NCE task. Consistent with this explanation, a positive effect is typically found when the primes are supraliminal (Eimer & Schlaghecken, 2002). In our Experiment 1, this executive process became partially unavailable because of the interference from the backward-counting task leading to the emergence of an inverted SRC pattern similar to the typical NCE.

A similar inverse effect was recently reported by Kostov & Janyan (2015) under the conditions when irrelevant activation must first be inhibited but should shortly be accessed again, to provide the actual response. Although the reported effects seem comparable, their origins are different. The process we propose cannot stem from attention, either visual or cross-modal. First, a visual attention explanation is insufficient because we found the inverse pattern using non-overlapping modalities (while obtaining the classical SRC effect in the control condition). Second, the general attentional account is implausible either since we found a different pattern in Experiment 2 where the same dual-task paradigm was used in non-overlapping modalities, but with a different type of interference. Moreover, as mentioned above, the Incongruent Stroop condition impaired the performance of the SRC task more severely than the backward-counting task. Taken together, the presence of the inverse SRC effect in presence of a backward-counting task cannot be explained by attentional demands or by the overall relative complexity of the task.

Relevance monitoring and self-inhibition

A negative compatibility pattern similar to the present one was obtained in the study by Ellis, Tucker, Symes, & Vainio (2007). In the presence of a congruent distractor, participants responded slower to the targets compatible with a response movement (precision or power grip) than on incompatible ones. The authors concluded that a top-down inhibition of the distractor-related affordance led to slower RTs when participants needed to produce the response to the target. Caligiore et al. (2013) recently replicated this pattern in a computational simulation study. The computational model they used, TRoPICALS, incorporated an executive control mechanism associated with the prefrontal cortex. When prefrontal areas produced a positive bias (facilitation) towards a task-relevant action, positive SRC effects were observed; a negative bias (inhibition) towards a distractor-related action led to NCE-like effect.

This reasoning together with the self-inhibition theory (Eimer & Schlaghecken, 2003) may imply a somewhat different perspective on the monitoring mechanism that we propose here: instead of verifying the relative *level* of the bottom-up activation as being permitted (not too high), the system may instead monitor the relevance of this activation. Hence, it could merge the top-down information about the task requirements and the bottom-up information about potential object-related actions (Caligiore et al., 2013). If these are complementary (prime is directly relevant), a response is facilitated; if they are inconsistent (prime is irrelevant), a response is inhibited. From this perspective, the usual functioning of the monitoring mechanism observed in Experiment 1 was disrupted by the backward-counting task. When, on a given Interference trial, the top-down information regarding the task requirements (identification of a stimulus as corresponding to a particular response option) was unavailable or delayed, it was impossible to verify the potential relevance of a bottom-up activated action representation. Consequently, as we suggested above, the threshold for self-inhibition dropped, and the negative compatibility pattern was observed. Since the self-inhibition is triggered in response to (irrelevant) activations of action plans, the relevance monitoring explanation is also consistent with the absence of any compatibility effects (classical or inverse) under interference in Experiment 2: The processing of an object was not deep enough to activate any associated action plans.

Theoretically, the activation monitoring explanation implies that the mechanism of monitoring itself becomes unavailable; the relevance monitoring explanation, instead, implies that the required information is unavailable. The activation monitoring account is more straightforward with respect to the observed pattern than the relevance monitoring account. However, the relevance monitoring account fits well with the existing theory as well as with the previous data reports. As indicated above, this account is consistent with the recent computational model (TRoPICALS; Caligiore et al., 2013) and some well-known results (Ellis et al., 2007). In other words, these two accounts represent a trade-off between an explanation's simplicity and its fit to the existing knowledge in the field. Since these accounts are well suited for the present results, both of them are considered here as viable.

However, the question regarding the exact nature of the monitoring mechanism proposed for the inversed effect remains open. Because of the different effect of the Stroop task and its relatively higher demands, this process could be somewhat specific to operations performed in the backward-counting task. For instance, it could be related to the stage of subtraction performance rather than the initial stage when attention is directed to the sound stimulus. To explore this issue further, other theoretically justified types of interference should be tested in future studies. Further, adapting the NCE-related paradigms for the investigation of affordances effects when the self-inhibition mechanism is manipulated (see, e.g. a study by Vainio et al., 2014) would provide an opportunity for a direct test of connections between the mechanisms of the NCE and affordances effects. Finally, according to our current interpretation, the self-inhibition mechanism does not disengage completely in supraliminal conditions; instead, its threshold is raised. Thus, it still can be accessed when the irrelevant action-related activation is sufficiently high, which should result in the registration of a similar NCE pattern. Consequently, the representation's strength can be manipulated to test this suggestion. Therefore, a further way to induce the inverse SRC effect might be by increasing the level of action-related activation. This can be achieved in future investigations, for example, using transcranial magnetic stimulation technique to activate motor hand-related areas while participants perform the SRC task.

Acknowledgments We wish to thank Dr. Alexey Kotov for his comments on earlier versions of the manuscript and for his help with the data collection, as well as Dr. Nikola Vukovic for his comments on the materials and procedure of Experiment 2. This research was supported by the Russian Foundation for Basic Research (RFBR) Grant 15-06-02233 A and by the Russian Academic Excellence Project '5-100'. The article was prepared within the framework of a subsidy granted to the HSE by the Government of the Russian Federation for the implementation of the Global Competitiveness Program.

Compliance with ethical standards

Conflict of interest Nikolay Dagaev declares that he has no conflict of interest. Yury Shtyrov declares that he has no conflict of interest. Andriy Myachykov declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

Anderson, S.J., Yamagishi, N., Karavia, V. (2002). Attentional processes link perception and action. *Proceedings of the Royal Society Series B. 269*, 1225–1232.

Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology: Section A, 49*(1), 5–28.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological), 57*(1), 289–300.

Binkofski, F., & Buxbaum, L. J. (2013). Two action systems in the human brain. *Brain and Language, 127*(2), 222–229.

Boccardi, E., Della Sala, S., Motto, C., & Spinnler, H. (2002). Utilisation behaviour consequent to bilateral SMA softening. *Cortex, 38*(3), 289–308.

Borghi, A.M. (2012). Action language comprehension affordances and goals. In Coello Y, Bartolo A (eds) *Language and action in cognitive neuroscience*. Psychology Press, pp 531–556.

Borghi, A. M., & Riggio, L. (2009). Sentence comprehension and simulation of object temporary canonical and stable affordances. *Brain Research, 1253*, 117–128.

Boy, F., Husain, M., & Sumner, P. (2010). Unconscious inhibition separates two forms of cognitive control. *Proceedings of the National Academy of Sciences, 107*(24), 11134–11139.

Bub, D. N., & Masson, M. E. J. (2010). Grasping beer mugs: on the dynamics of alignment effects induced by handled objects. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 341–358.

Buccino, G., Sato, M., Cattaneo, L., Rodà, F., & Riggio, L. (2009). Broken affordances, broken objects: a TMS study. *Neuropsychologia, 47*(14), 3074–3078.

Caligiore, D., Borghi, A. M., Parisi, D., Ellis, R., Cangelosi, A., & Baldassarre, G. (2013). How affordances associated with a distractor object affect compatibility effects: a study with the computational model TRoPICALS. *Psychological Research, 77*(1), 7–19.

Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 362*(1485), 1585–1599.

Cisek, P., & Kalaska, J. F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual Review of Neuroscience, 33*, 269–298.

Eimer, M. (1999). Facilitatory and inhibitory effects of masked prime stimuli on motor activation and behavioral performance. *Acta Psychologica, 101*, 293–313.

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*(6), 1737–1747.

Eimer, M., & Schlaghecken, F. (2003). Response facilitation and inhibition in subliminal priming. *Biological Psychology, 64*(1–2), 7–26.

Eimer, M., Schubö, A., & Schlaghecken, F. (2002). The locus of inhibition in the masked priming of response alternatives. *Journal of Motor Behaviour, 34*, 3–10.

Ellis, R., Tucker, M., Symes, E., Vainio, L. (2007). Does selecting one visual object from several require inhibition of the actions associated with non-selected objects? Journal of Experimental Psychology: Human Perception and Performance, 33, 670–691.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16*(1), 143–149.

Fischer, M. H., & Dahl, C. (2007). The time course of visuo-motor affordances. *Experimental Brain Research, 176*(3), 519–524.

Geusebroek, J. M., Burghouts, G. J., & Smeulders, A. W. M. (2005). The Amsterdam library of object images. *International Journal of Computer Vision, 61*(1), 103–112.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton.

Handy, T.C., Borg, J.S., Turk, D.J., Tipper, C.M., Grafton, S.T., Gazzaniga, M.S. (2005). Placing a tool in the spotlight: Spatial attention modulates visuomotor responses in cortex. *NeuroImage*, *26*, 266–276.

Handy, T. C., Grafton, S. T., Shroff, N. M., Ketay, S., & Gazzaniga, M. S. (2003). Graspable objects grasp attention when the potential for action is recognized. *Nature Neuroscience, 6*, 421–427.

Hedge, A., & Marsh, N. W. A. (1975). The effect of irrelevant spatial correspondences on two-choice response-time. *Acta Psychologica, 39*(6), 427–439.

Jax, S. A., & Buxbaum, L. J. (2010). Response interference between functional and structural actions linked to the same familiar object. *Cognition, 115*(2), 350–355.

Jonides, J., & Irwin, D. E. (1981). Capturing attention. *Cognition, 10*(1), 145–150.

Klapp, S. T., & Hinkley, L. B. (2002). The negative compatibility effect: unconscious inhibition influences reaction time and response selection. *Journal of Experimental Psychology: General, 131*, 255–269.

Koechlin, E., Ody, C., & Kouneiher, F. (2003). The architecture of cognitive control in the human prefrontal cortex. *Science, 302*(5648), 1181–1185.

Kostov, K., & Janyan, A. (2012). The role of attention in the affordance effect: can we afford to ignore it? *Cognitive Processing, 13*, 215–218.

Kostov, K., & Janyan, A. (2015). Reversing the affordance effect: negative stimulus–response compatibility observed with images of graspable objects. *Cognitive Processing, 16*(1), 287–291.

Kourtis, D., & Vingerhoets, G. (2015). Perceiving objects by their function: An EEG study on feature saliency and prehensile affordances. *Biological Psychology, 110*, 138–147.

Lhermitte, F. (1983). 'Utilization behaviour' and its relation to lesions of the frontal lobes. *Brain*, *106*, 237–255.

Makris, S., Hadar, A. A., & Yarrow, K. (2011). Viewing objects and planning actions: on the potentiation of grasping behaviours by visual objects. *Brain and Cognition, 77*(2), 257–264.

Makris, S., Hadar, A. A., & Yarrow, K. (2013). Are object affordances fully automatic? A case of covert attention. *Behavioral Neuroscience, 127*(5), 797.

Makris, S., & Yarrow, K. (2014). Unconscious presentation of object affordances evokes a negative compatibility effect. i-Perception, 5(5), 489-489.

McBride, J., Sumner, P., & Husain, M. (2012). Conflict in object affordance revealed by grip force. *The quarterly journal of experimental psychology, 65*(1), 13–24.

McBride, J., Sumner, P., Jackson, S. R., Bajaj, N., & Husain, M. (2013). Exaggerated object affordance and absent automatic inhibition in alien hand syndrome. *Cortex, 49*(8), 2040–2054.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100.

Morgan, A. L. R., & Brandt, J. F. (1989). An auditory Stroop effect for pitch, loudness, and time. *Brain and Language, 36*(4), 592–603.

Muthukumaraswamy, S. D., Johnson, B. W., & McNair, N. A. (2004). Mu rhythm modulation during observation of an object-directed grasp. *Cognitive Brain Research, 19*(2), 195–201.

Myachykov, A., Ellis, R., Cangelosi, A., & Fischer, M. (2013). Visual and linguistic cues to graspable objects. *Experimental Brain Research, 229*(4), 545–559.

Norman, D. A., & Shallice, T. (2000). *Attention to action: Willed and automatic control of behavior* (pp. 376–390). Cognitive neuroscience: A reader.

Pappas, Z. (2014). Dissociating Simon and affordance compatibility effects: Silhouettes and photographs. *Cognition, 133*(3), 716–728.

Pappas, Z., & Mack, A. (2008). Potentiation of action by undetected affordant objects. Visual Cognition, *16*(7), 892–915.

Peirce, J. W. (2007). PsychoPy - psychophysics software in Python. *Journal of Neuroscience Methods, 162*(1), 8–13.

Pellicano, A., Iani, C., Borghi, A. M., Rubichi, S., & Nicoletti, R. (2010). Simon-like and functional affordance effects with tools: The effects of object perceptual discrimination and object action state. *The Quarterly Journal of Experimental Psychology, 63*(11), 2190–2201.

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*(3), 193–198.

Phillips, J.C., & Ward, R. (2002). S-r correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual Cognition*, *9*(4–5), 540–558.

Posner, M. I., & Dehaene, S. (1994). Attentional networks. *Trends in Neurosciences, 17*(2), 75–79.

Proverbio, A. M. (2012). Tool perception suppresses 10–12 Hz μ rhythm of EEG over the somatosensory area. *Biological Psychology, 91*(1), 1–7.

Proverbio, A. M., Adorni, R., & D'Aniello, G. E. (2011). 250 ms to code for action affordance during observation of manipulable objects. *Neuropsychologia, 49*(9), 2711–2717.

Righi, S., Orlando, V., & Marzi, T. (2014). Attractiveness and affordance shape tools neural coding: insight from ERPs. *International Journal of Psychophysiology, 91*(3), 240–253.

Roberts, K. L., & Hall, D. (2008). Examining a supramodal network for conflict processing: a systematic review and novel functional magnetic resonance imaging data for related visual and auditory stroop tasks. *Journal of Cognitive Neuroscience, 20*(6), 1063–1078.

Schlaghecken, F., & Eimer, M. (2000). A central/peripheral asymmetry in subliminal priming. *Perception and Psychophysics, 62*, 1367–1382.

Schlaghecken, F., & Eimer, M. (2002). Motor activation with and without inhibition: evidence for a threshold mechanism in motor control. *Perception and Psychophysics, 64*, 148–162.

Shallice, T., Burgess, P. W., Schon, F., & Baxter, D. M. (1989). The origins of utilization behaviour. *Brain, 112*, 1587–1598.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology, 81*(1), 174.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643–662.

Sumner, P. (2007). Negative and positive masked-priming–implications for motor inhibition. *Advances in Cognitive Psychology, 3*(1–2), 317–326.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive science, 12*(2), 257–285.

Symes, E., Ellis, R., & Tucker, M. (2005). Dissociating object-based and space-based affordances. *Visual Cognition, 12*(7), 1337–1361.

Symes, E., Ellis, R., & Tucker, M. (2007). Visual object affordances: Object orientation. *Acta Psychologica, 124*(2), 238–255.

Szameitat, A. J., Schubert, T., Müller, K., & Von Cramon, D. (2002). Localization of executive functions in dual-task performance with fMRI. *Journal of Cognitive Neuroscience, 14*(8), 1184–1199.

Thill, S., Caligiore, D., Borghi, A.M., Ziemke, T., Baldassarre, G. (2013). Theories and computational models of affordance and mirror systems: An integrative review. *Neuroscience and Biobehavioral Reviews*, *37*, 491–521.

Tipper, S.P., Paul, M.A., Hayes, A.E. (2006). Vision for action: the effects of object property discrimination and action state on affordance compatibility effects. *Psychonomic Bulletin and Review*, 13(3), 493–498.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 830–846.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. Visual Cognition, 8, 769–800.

Vainio, L., Ala-Salomäki, H., Huovilainen, T., Nikkinen, H., Salo, M., Väliaho, J., & Paavilainen, P. (2014). Mug handle affordance and automatic response inhibition: Behavioural and electrophysiological evidence. *The Quarterly Journal of Experimental Psychology, 67*(9), 1697–1719.

Vainio, L., Ellis, R., Tucker, M. (2007). The role of visual attention in action priming. The Quarterly Journal of Experimental Psychology, 60, 241-261.

Whitaker, L. A. (1979). Dual-task interference as a function of cognitive processing load. *Acta Psychologica, 43*(1), 71–84.

Wilf, M., Holmes, N. P., Schwartz, I., & Makin, T. R. (2012). Dissociating between object affordances and spatial compatibility effects using early response components. *Frontiers in Psychology*, 4.