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Living on the edge: strategic and instructed slowing in the stop signal task

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Abstract The stop signal task is widely adopted to assess motor inhibition performance in both clinical and non-clinical populations. Several recent studies explored the influence of strategic approaches to the task. In particular, response slowing seems to be a strategic approach commonly adopted to perform the task. In the present study, we compared a standard version with a strategic version of the task, in which participants were explicitly instructed to slow down responses. Results showed that the instructed slowing did not affect the main inhibition measure, thus confirming the robustness of the stop signal index. On the other hand, it apparently changed the nature of the task, as shown by the lack of correlation between the standard and the strategic versions. In addition, we found a specific influence of individual characteristics on slowing strategies. In the standard version, adherence to task instructions was positively correlated with compliant traits of personality. Despite instructions to maximize response speed, non-compliant participants preferred to adopt a slowing strategy in the standard version of the task, up to a speed level similar to the strategic version, where slowing was required by task instructions. Understanding the role of individual approach to the task seems to be crucial to properly identify how participants cope with task instructions.

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Introduction

The ability to terminate an action that is no longer suitable, such as stop the car when the traffic light turns red, is a direct expression of motor inhibition processes. This self-regulatory function is fundamental for goal-directed actions in everyday life. The Stop Signal Task (SST) (Logan & Cowan, 1984; Logan, 1994) is considered to be a reliable paradigm to estimate, in an experimental setting, the ability to suppress a programmed motor action. Usually participants are required to perform a primary task (e.g. shape discrimination). The paradigm encompasses both "go trials" and "stop trials". In the go trials, participants are asked to perform the primary task whereas, in the stop trials, a stop signal (e.g. a sound) is delivered and participants must withhold their response. The paradigm is theoretically-rooted in the "horse race" model (Logan & Cowan, 1984) where the go process is supposed to run in parallel with the stop process. If the go process ends first, the motor action is performed. Conversely, if the stop process ends first, the response is inhibited. The imbalance between the onsets of the go and stop processes is indexed by the Stop Signal Delay (SSD), that is, the time interval between the target and the stop signal. Typically this delay is dynamically tracked from an initial duration of some hundreds of milliseconds. If, in one trial, the motor inhibition happens to be successful, the stop signal is slightly postponed in the subsequent stop trial; vice versa, when motor inhibition is unsuccessful, the SSD is slightly reduced on the subsequent stop trial.

Notably, the SSD is heavily influenced by individual inhibition success. In contrast, the Stop Signal Reaction Time (SSRT, Logan & Cowan, 1984; Logan, Schachar, & Tannock, 1997) is considered to be a more reliable index of motor inhibition, because it is thought to be independent, given its adaptive nature, of the individual response speed. The SSRT is usually calculated by subtracting the mean SSD from the mean RT in go trials. A relatively short SSRT reflects a shorter internal inhibitory response to the stop signal (i.e. faster stopping process), independently of the early or late occurrence of the stop signal itself.

Several studies employing the SST have shown that deficits in inhibitory processes, indexed by longer SSRTs, characterize several pathologies, such as traumatic brain injury (Floden & Stuss, 2006; Stewart & Tannock, 1999), obsessive–compulsive disorder (Chamberlain, Fineberg, Blackwell, Robbins, & Sahakian, 2006) and attention deficit hyperactivity disorder (for a review see Lijffijt, Kenemans, Verbaten, & van Engeland, 2005). Also individual characteristics influence the SSRT value: as an example, the most impulsive participants present longer SSRTs (e.g. Lansbergen, Schutter, & Kenemans, 2007; Logan et al., 1997), indexing worse inhibitory abilities.

Individual tendencies/characteristics have been recently proposed as being crucial to understand group data. Fundamentally, participants are thought to balance two aspects of task instructions: fast responses in the go trials (i.e. target discrimination task) and successful inhibitions in stop trials. Several theories have been proposed to explain how participants approach the task (for a review see Bissett & Logan, 2011). In particular, the goal priority hypothesis claims that participants tend to slow down RTs in go trials to enhance the probability of a successful inhibition in stop trials (Leotti & Wager, 2010; Liddle et al., 2009). In this regard, Verbruggen and Logan (2009) demonstrated that the RTs in go trials can be proactively modified by asking participants (even on a trial-by-trial basis) to consider (or disregard) the stop signals. In their study, participants speeded up responses when the stop signal had to be ignored, whereas, in line with the goal priority hypothesis, they slowed their responses when they had to consider stop signals. Group data indexed a strategic slowing of responses as if some (or all) participants were expecting the stop signal occurrence, in analogy with the detrimental effects on a primary task found under dual-task conditions (Pashler, 1994). Participants are likely to trade-off speed for accuracy, instead of equally considering both aspects of the instructions, that is fast responses in go trials and inhibition in stop trials. Leotti and Wager (2010) reported that individual compliance with task instructions is tightly linked with behavioral performance. Indeed, they examined the performance of participants who were not compliant with the instructions by selecting those with an inhibition ratio greater than 0.6. This sub-group of participants progressively reduced speed throughout the task, thus increasing the probability of successful inhibition in stop trials. These non-compliant participants showed a reduced SSRT with respect to the compliant ones, as if they presented a better inhibition performance. This finding suggests that a strategic approach to the task can influence the SSRT, that is an index supposed to be insensitive to the adoption of slowing strategies. Consequently, exploring how slowing strategies are implemented to solve the task seems to be crucial not only to exclude potential confounds but also for a proper and direct investigation of the task itself. It thus seems to be mandatory to have a deeper understanding of the relation between slowing strategies and individual traits. Instead of an a posteriori categorization of the participants on the basis of their performance, we deemed as appropriate to assess individual characteristics of compliance with a stringent a priori method, by administering a personality inventory to each participant.

In the present study, we implemented a new manipulation that consisted of explicitly instructing participants to reduce their response speed in a strategic version of the task. This approach allowed us to appreciate to what extent an explicitly-suggested strategy can influence measures of motor inhibition with respect to a standard version of the task where participants were required not to slow their responses. We then implemented a fine-grained analysis based upon the comparison of the performance of the same group of participants across the standard SST and the strategic SST with respect to a speed-block task. The speed-block was intended as a baseline measure of response speed, where participants were presented with go trials only and were instructed to ignore the stop signal. This block provided a genuine measure of the go process with no influence due to the stop process. In the standard version we implemented a classic SST where instructions stressed both speed of response and inhibition in stop trials. In the strategic version, we presented the same stimuli of the standard version but participants were explicitly instructed to slow down RTs in go trials. We tested whether an instructed slowing might influence SSRT in a way similar to the strategic slowing which is expected to be spontaneously adopted by some participants in the standard version, despite the fact that instructions explicitly stressed the importance of fast responses. By means of these tasks, we explored not only whether speed-accuracy trade-off can influence SSRT, as done by Leotti and Wager (2010), but, in addition, we also tested whether the influence of speed-accuracy trade-off is related to individual traits. If speed-accuracy trade-off is strategically implemented by all participants also in the standard version, no differences with respect to the strategic version, where slowing is required by task instructions, are expected. In contrast, if only some participants consistently adopt slowing strategies in the SSRT, significant differences with respect to the strategic version should emerge.

Method

Participants

21 right-handed students (6 males) of the University of Padova, aged from 21 to 32 ($M_{age} = 23.2 \pm 2.8$), took part in the experimental session for a payment of 13 euro, after having provided their informed consent. Participants declared: (a) neither any past or present psychiatric disorders nor episodes of severe brain injury; (b) to have assumed neither psychotropic substances nor psycho-pharmaceuticals in the last 4 weeks; (c) to have normal or corrected to normal vision; (d) not to have auditory deficits.

Procedure

Participants sat in a quiet room at approximately 60 cm from a 15-inch monitor controlled by a PC desktop with a 2 GHz processor. The experimental session lasted for about 1 h and started with the speed-block. Then, the standard version and the strategic version were presented, counterbalanced between participants. Afterwards, each participant completed the Impulsivity–Venturesomeness–Empathy Questionnaire (IVE; Eysenck & Eysenck, 1969). This questionnaire allows one not only to control for impulsivity traits, known to affect performance in SST, but also to specifically measure the compliance of participants, which we thought was well accounted for by the empathy sub-scale, containing several items measuring the subjective emotional and cognitive "tuning" to implicit needs and explicit requirements of the other people.

Stimuli

In the speed-block, each trial began with a central fixation cross lasting for a random interval ranging from 500 to 1,500 ms. Then, a geometrical shape (e.g. a circle or a square; approximately 3.5 cm width) was presented in the centre of the screen.

Participants had to press the "M" or "Z" key, with the right or left index finger, respectively, (standard QWERTY keyboard) according to the stimulus type (e.g. a circle or a square). The time limit allowed for response was 1 s. Response key assignment was counterbalanced between participants. In 25% of trials, a "beep" sound (72 dB, 50 Hz) was randomly delivered for 50 ms through earphones. Participants were instructed to respond to the visual stimulus as fast as possible and to ignore the "beep" sound. Incorrect and omitted responses were followed by the "wrong" and "time over" feedbacks, respectively, for 750 ms, whereas correct responses were followed by a blank screen with the same duration as the feedback. The task was composed of six blocks, with ten trials each. At the end of each block, participants received a feedback based on their mean RT. A positive feedback ("good!") was released if the participant had been faster than the best mean RT previously obtained. A negative feedback ("too slow!") was released if the participant had been slower than the mean RT previously obtained. This task was intended to provide a baseline measure of participants' speed in performing the shape discrimination task without any cost due to the pre-activation of stop processes.

In the standard version, the stimuli were the same as in the speed-block task. There were 384 trials divided into 3 blocks (128 each). Participants were explicitly instructed to respond to the stimuli as fast as possible and to withhold their response when the sound was delivered. The feedback "wrong" was presented when the participant responded despite the presence of the stop signal. The time interval between the target stimulus and the stop signal (i.e. SSD), initially set to 250 ms, was dynamically tracked: when the inhibition of the response was successful, the stop signal was postponed by 50 ms in the subsequent stop trial. If the participant was not able to inhibit the response, the sound was anticipated by 50 ms in the subsequent stop trial. At the end of each block, participants were allowed to rest for about 1 min.

The strategic version was identical to the standard version except for instructions; participants were told to slow down their response speed "to increase the chance to successfully inhibit the response when required".

Results

We performed four analyses on: (a) the differences between the standard and the strategic versions of the task (Table 1); (b) the presence of slowing in the standard version of the task; (c) the effect of slowing and other predictors on the SSRT in both tasks; and (d) the relation between slowing and compliance.

Standard versus strategic

We analyzed mean RTs in go trials, percentage of slowing, accuracy in go trials, accuracy in stop trials, percentage of omissions, and the SSRT separately in a series of 2 × 2 mixed ANOVAs with task [Standard, Strategic] as a within-participants factor and order of presentation [1st, 2nd] as between-participants factor. In all the ANOVAs the effect of order of presentation failed to reach significance.

Table 1 Descriptive statistics for speed-block, standard and strategic versions of the task

Measure	Task		
	Speed-block M (SD)	Standard M (SD)	Strategic M (SD)
Mean RT go trials (ms)	417 (36)	607 (91)	712 (71)
SSD (ms)	–	391	492
SSRT (ms)	–	232 (22)	240 (31)
Slowing (%)	–	32 (14.8)	50 (12.1)
Error in go trials (%)	3.6 (3.6)	0.81 (0.86)	0.59 (1.1)
Accuracy in stop trials (%)	–	56 (4.6)	59 (2.9)
Omissions (%)	0.3 (0.8)	2.6 (2.5)	6.2 (3.9)

The SSD (Stop Signal Delay) indexes the time interval between the target and the stop signal. The SSRT (Stop Signal Reaction Time) indexes the inhibition efficacy and is calculated comparing the SSD and response speed in go trials (see text for further details). The slowing percentage indexes the mean slowing in the two versions of the task calculated with respect to the performance in the speed-block

The main effect of task was significant for RTs in go trials, $F(1, 19) = 27.32$, $p < 0.001$, $\eta_p^2 = 0.590$: participants responded faster in the standard version ($M = 607$ ms, SD = 91) than in the strategic version ($M = 712$ ms, SD = 71). For each participant, we calculated also the percentage of slowing with respect to the mean individual RT performance in the speed-block and to the maximal trial length (1 s). The formulas adopted were: for the standard version [(mean RT go trials standard version−mean RT speed-block)/(1,000 ms−mean RT speed block)] × 100; for the strategic version [(mean RT go trials strategic−mean RT speed-block)/(1,000 ms−mean RT speed-block)] × 100.[1] Notably, the modality adopted here to calculate the percentage of slowing allows one to determine very precisely the individual slowing rate, because it refers to the amount of time truly available for slowing for each participant [i.e. maximal time for response (e.g. 1 s)−speed-block RT]. The main effect of task was significant for the percentage of slowing, $F(1, 19) = 29.2$, $p < 0.001$, $\eta_p^2 = 0.606$, showing that percentage of slowing was higher in the strategic ($M = 50\%$, SD = 12.1) than in the standard version ($M = 32\%$, SD = 14.8). We can thus conclude that participants were able to adapt their performance to the task demands, effectively allocating their cognitive resources according to the instructions.

[1] For instance, if a participant reached a mean RT of 450 ms in the speed-block, of 600 ms in the standard version and of 750 ms in the strategic version, the resulting percentage of slowing would have been 27% [(600−450)/(1,000−450)] for the standard version, and 55% [(750−450)/(1,000−450)] for the strategic version.

Regarding performance in shape discrimination (go trials only), participants made an almost equal percentage of errors in the strategic ($M = 0.59\%$, SD = 1.1) and in the standard version ($M = 0.81\%$, SD = 0.86), $F(1, 19) = 1.68$, $p = 0.210$, $\eta_p^2 = 0.081$.

We then calculated the actual accuracy in withholding the response in stop trials, which was expected to be about 50%, because of the individual calibration procedure. Accuracy in withholding the response was higher in the strategic version ($M = 59\%$, SD = 2.9) with respect to the standard version ($M = 56\%$, SD = 4.6), as indexed by a main effect of task, $F(1, 19) = 11.92$, $p = 0.003$, $\eta_p^2 = 0.386$.

The percentage of omissions varied between the two versions of the task, $F(1, 19) = 15.06$, $p = 0.001$, $\eta_p^2 = 0.442$, with more omissions in the strategic version ($M = 6.2\%$, SD = 3.9) than in the standard ($M = 2.6\%$, SD = 2.5). This effect was plausibly due to participants' attempts to postpone the response as much as possible, thus increasing the number of responses provided after 1 s.

Finally, we calculated the SSRT according to a variant of the integration method, optimized for tracking procedure, when the chance to inhibit the response differs from 0.5 (Logan, 1994; Yamaguchi, Logan, & Bissett, 2012). For each participant, we selected the go RT corresponding to the nth percentile of the distribution where n is the percentage of accuracy in the stop trials (i.e. inhibition ratio). The individual SSD was then subtracted from the selected RT, thus obtaining the SSRT for each participant. The standard version yielded a mean of 232 ms (SD = 22) and the strategic version yielded a mean of 240 ms (SD = 31). The difference between the two versions of the task was not significant, $F(1, 19) = 1.76$, $p = 0.201$, $\eta_p^2 = 0.089$. This result suggests that the SSRT value is indeed robust and relatively independent of the adoption of slowing strategies, explicitly required by the task instruction in the strategic version. However, we found a non-significant correlation between the SSRTs of the two tasks, $r = 0.08$, $p = 0.721$, as if the individual cognitive processes underpinning the same SSRT effect were different in nature.

Strategic slowing in the standard version

The small difference between RTs in the strategic and the standard versions suggests that some participants might have slowed down their responses also in the standard version. Therefore, we ran a discriminant analysis to explore how many participants slowed their responses in the standard version of the task consistently enough to reach a speed level as low as the one showed in the strategic version. The grouping variable was task [standard, strategic, coded 0–1] and the independent variable was the percentage of slowing. Six participants out of 21 (28%) were

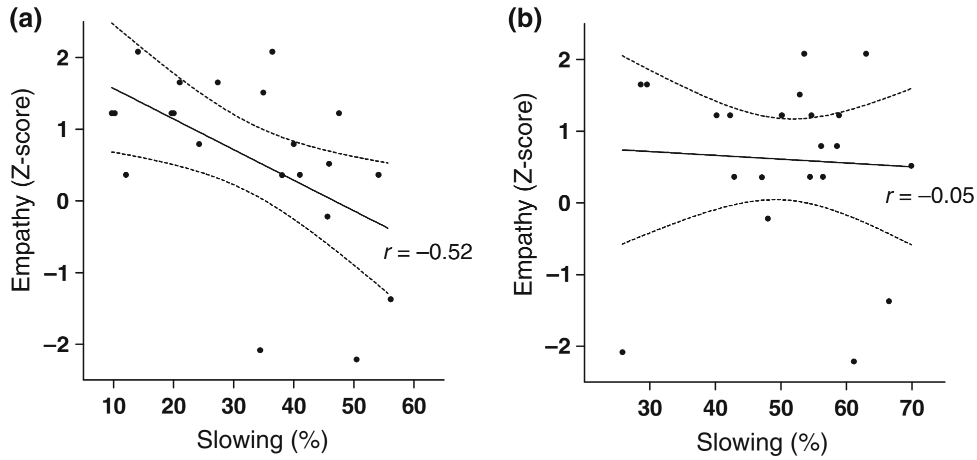

Fig. 1 Individual percentage of slowing is shown with respect to the IVE Empathy Z-score for the standard (*panel a*) and the strategic (*panel b*) versions of the task. The percentage of slowing showed a significant negative correlation with the IVE Empathy Z-score in the standard (Straight line, $r = -0.52$, $p < 0.05$) but not in the strategic version ($r = -0.05$, ns) of the task. Dashed lines represent 95% C.I

categorized as adopting a strategic slowing in the standard version, $\lambda = 0.685$, $\chi^2(1) = 14.67$, $p < 0.001$. It could be argued that participants were influenced by order of presentation, because performing the strategic version first might drive participants to reduce speed also in the subsequent standard version. This is not the case because among the participants who completed the standard version first, three out of 11 (27%) were classified as adopting a strategic speed-accuracy trade-off in the standard version. We then compared the performance of the sub-group of slow responders (6 participants), exhibiting a slowing strategy also in the standard version, with the performance of the remaining participants. The slow responders showed, rather obviously, a higher percentage of slowing ($M = 50\%$, $SD = 4$) in the standard version as compared to the other participants ($M = 26\%$, $SD = 11$), $t(19) = 5.08$, $p < 0.001$. Less obviously, their increased slowing extended to the strategic version (slow responders: $M = 59\%$, $SD = 8$; rest of the group: $M = 47\%$, $SD = 11$), $t(19) = 2.26$, $p = 0.036$. Interestingly, the sub-group of slow responders also obtained a better inhibition accuracy in the standard version ($M = 61\%$, $SD = 2$) as compared to the other participants ($M = 54\%$, $SD = 4$), $t(19) = 3.67$, $p = 0.002$.

Slowing and SSRT

We further explored the across-tasks relation between slowing, individual traits and SSRT. To do so, we ran two linear regressions analyses, separately for the standard and for the strategic versions of the task, with the SSRT as response variable and age, compliance (as measured by the IVE Empathy subscale), impulsivity (IVE impulsivity subscale) and percentage of slowing as predictors. For both standard and strategic versions, none of the variables significantly predicted the SSRT value. Only the percentage of slowing in the strategic version approached significance in predicting an increased SSRT, $p = 0.052$. Inhibition performance might have been negatively affected by an excessive tendency to postpone the responses while waiting for the potential occurrence of the stop signal.

Slowing and compliance

Given the results of Leotti and Wager (2010), suggestive of a role of individual adherence to the instructions on performance, we performed a detailed investigation of the relation between slowing and compliance in the two versions of the task. We analyzed the percentage of slowing in a 2 × 2 mixed ANCOVA with task [standard, strategic] as within-participants factor, order of presentation [1st, 2nd] as between-participants factor, and compliance (Empathy subscale of IVE) as covariate. We found a significant interaction between task and compliance, $F(1,\ 18) = 5.16$, $p = 0.036$, $\eta_p^2 = 0.223$, and no interaction between task and order, $F < 1$. To examine the impact of compliance on the two versions of the task, we performed two separate regression analyses with slowing as response variable and compliance as predictor. In the standard version of the task compliance was, crucially, a significant predictor, $t(20) = 2.68$, $p = 0.015$, whereas it was far from significance in the strategic version, $t(20) = 0.232$, $p = 0.819$ (Fig. 1). The relation between compliance and slowing was confirmed by the lower Empathy score presented by the subgroup of the slow responders with respect to the remaining participants, $t(19) = 2.36$, $p < 0.05$.

General discussion

In the present study we explored the influence of slowing strategies and individual compliance in inhibition performance. To do so, we adopted a speed-block task and two different versions of the SST. The speed-block was a baseline task intended to selectively assess go processes where participants were asked to ignore the stop signal. In contrast, in the standard version, we asked participants to perform a classic SST, namely, to continue to respond as fast as possible in go trials but to withhold responses in the stop trials. In the new and crucial strategic version implemented in our study, participants were explicitly required to slow responses in go trials.

Ideally, the speed-block and the standard version should have led to a similar response speed. In fact, the large difference between the mean RTs in the two tasks testifies that this is not what usually happens, here as in previous studies. It appears, therefore, important to calculate indexes specifically designed to take into account the slowing that can be adopted by participants. Stemming from this perspective, we performed a detailed analysis of the individual approaches that can be put into act when balancing performance priorities across different task demands. Indeed, we have shown that some participants implemented the slowing strategies also in the standard version of the task, reaching a percentage of slowing similar to the strategic version. Although the explicit suggestion to implement a slowing strategy did not globally alter inhibition performance, it deeply affected the way participants performed the task. Given that the SSRTs in the two versions of the task were uncorrelated, it can be then argued that the standard and the strategic versions of the task may be different in nature.

We interpret our findings in light of the recent studies that have examined, to better characterize individual strategic approaches to the task, not only the simple inhibitory process but also individual changes in speed and accuracy. The evidence provided here is compatible with the goal priority hypothesis (Leotti & Wager, 2010; Liddle et al., 2009), which maintains that participants tend to slow down in go trials to improve their chance of successful inhibitions in the stop trials. On top of that, our investigation confirms that individual traits of personality can influence the approach to the task. We showed that individual compliance, as a priori measured by means of personality traits, significantly predicts individual speed-accuracy trade-off. Thus, in addition to previous studies that highlighted a key role for impulsiveness characteristics (Logan et al., 1997), we suggest that also compliant traits of personality might affect individual approach to the task. Indeed, participants who resulted as being more compliant in a personality inventory were also more compliant with task instructions, and did not reduce response speed in the standard version of the task.

Broadly speaking, our results confirmed that participants modify speed of response depending on instructions (Verbruggen & Logan, 2009). Overall, a stable SSRT measure emerged across tasks, thus confirming its robustness to the adoption of slowing strategies. On the other hand, there was no correlation between SSRTs in standard and strategic versions; a crucial aspect of the data that suggests that the mechanisms underlying SSRT might differ according to the version of the task (Leotti & Wager, 2010). If the SSRT would have measured similar processes/abilities in the two versions, a significant positive correlation should have emerged. According to the evidence provided by our fine-grained comparison between the standard and the strategic version, we characterize the SSRT as a multi-componential index, where motor inhibition plays an important role, albeit not unique. Indeed, participants facing an SST task are free (either consciously or not) to modify their percentage of slowing and to prioritize one aspect or another of the task. The SSRT index might "summarize" several, potentially heterogeneous, cognitive processes; indeed, as suggested by Leotti and Wager (2010), when participants are not compliant with the instructions and, thus, reduce speed of response, they are in fact performing a decision-making task.

In our case, the most convincing evidence that distinct processes might underlie the different versions of the task comes from the analysis of the temporal differences between tasks. In the speed-block participants were able to discriminate the shape and provide a response within a time window as short as 400 ms. In the standard version, participants slowed responses as if they were performing a dual-task simultaneously aiming at balancing fast responses and inhibition performance. In the strategic version, the further slowing of responses might be suggestive of a sequential dual-task as if in the first stage participants discriminated the shape and decided the correct key for response, and then, in the subsequent second stage, they strategically waited for the potential occurrence of the stop signal. This aspect is rather critical because the experimenter has no hint on which kind of task a participant is actually performing. We highlight that our results have been based on the percentage of slowing, which we newly decided to calculate taking speed-block performance as baseline, and thus preventing any unwarranted individual influence due, for instance, to the presence of particularly slow participants. Our index of slowing thus should be considered a measure of how each participant individually deals with the time at disposal.

In addition, in our task, the sub-group of participants showing a higher percentage of slowing in the standard version was characterized by lower compliance and better inhibition accuracy. These findings confirm that, for some non-compliant participants, the slowing was truly strategic also in the standard version. Interestingly, this sub-group of participants obtained slower responses also in the strategic version: most likely, this tendency led them closer to the time limit allowed for response.

The link we found between slowing and inhibition accuracy confirms the results of the study by Leotti and Wager (2010), in which, following a complementary approach, a sub-group selected for high inhibition accuracy was characterized by slower responses. In contrast with their study, in our standard version, the percentage of slowing was not related to SSRT. This difference with respect to the Leotti and Wager study might be due to the shorter time limit (1 vs. 1.5 s) characterizing our task. The shorter time window allowed for responding plausibly played against the possibility to observe, in slow participants, a deployment of progressively slower responses, which was instead the focus of their study. This apparently negligible methodological difference might have thus determined whether participants were free or not to perseverate in their non-compliant approach within the same task.

To sum up, task instructions essentially indicate which aspect of the task prioritize. Despite these specific instructions, some of the participants adopt alternative response strategies, based on their own motivation (Leotti & Wager, 2010) and/or on the tentative to balance different aspects of the task (Bissett & Logan, 2011). These strategies were closely linked to individual characteristics, thus leaving the door open for a spontaneous, albeit undesirable (at least for the experimenter), subjective component.

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