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The boundary conditions for Bohr's law: when is reacting faster than acting?

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Abstract In gunfights in Western movies, the hero typically wins, even though the villain draws first. Niels Bohr (Gamow, *The great physicists from Galileo to Einstein. Chapter: The law of quantum*, 1988) suggested that this reflected a psychophysical law, rather than a dramatic conceit. He hypothesized that *reacting* is faster than *acting*. Welchman, Stanley, Schomers, Miall, and Bülthoff (*Proceedings of the Royal Society of London B: Biological Sciences, 277*, 1667–1674, 2010) provided empirical evidence supporting "Bohr's law," showing that the time to complete simple manual actions was shorter when reacting than when initiating an action. Here we probe the limits of this effect. In three experiments, participants performed a simple manual action, which could either be self-initiated or executed following an external visual trigger. Inter-button time was reliably faster when the action was externally triggered. However, the effect disappeared for the second step in a two-step action. Furthermore, the effect reversed when a choice between two actions had to be made. Reacting is faster than acting, but only for simple, ballistic actions.

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The great quantum physicist Niels Bohr also displayed a keen intuition for psychophysics. Bohr was a known aficionado of Hollywood westerns. George Gamow (1988, pp. 237–238) recounts an episode where Bohr watched a movie with several friends, and the group pondered the question of why the hero always wins gun duels, despite the fact that the villain inevitably acted first. Aside from dramatic necessity, Bohr asserted that this phenomenon reflected a fundamental law of human behavior: reacting is faster than acting. Since the villain draws first, he must initiate his own motion, thereby introducing thoughts and doubts into his action. The hero's action, meanwhile, is triggered by an external cue and is therefore not affected by these distracting thoughts. Gamow reports that Bohr and his friends tested the hypothesis empirically with toy guns the next day, but the anecdote does not tell whether this led to a statistically significant confirmation of Bohr's hypothesis. Note that, for the good guy to actually win the gun duel, the reactive advantage has to be rather substantial. The good guy will only initiate his action after he has processed the visual input that tells him that the bad guy has acted. This will give the villain a serious head start.

But there are more reasons to suspect that Bohr might be wrong. For both self-initiated and reactive movements, the action is carried out after the pre-motor planning has finished, since both parties have anticipated the action to be performed. Since all preparation for the action is over, why would it matter that the action was initiated or reactive? Furthermore, in the initiated case, a person will presumably only execute the motion if he feels totally ready for it, while in the reactive case, pre-motor programming might still be under way. Thus, if anything, one would expect initiated actions to be faster than reactive actions.

On the other hand, an indication that there might indeed be a difference between self-initiated and reactive actions comes from observations on patients with Parkinson's disease. In some of these patients, a curious phenomenon called "paradoxical kinesis" occurs. This phenomenon entails that patients are unable to initiate a certain action themselves, but they can perform this action when it is in reaction to an external event (Siegert, Harper, Cameron, & Abernethy, 2002).

Notice that we now have mentioned three ways in which actions and re-actions can differ. The time between wanting to act and having acted (the reaction time) may differ. There might be a qualitative difference (as with Parkinson patients). Finally, the time it takes to perform the action may differ. Here we focus on the third version of the hypothesis: we investigate whether the time it takes to execute an action is different for initiated and reactive actions.

Studies investigating the differences between initiated and reactive actions in non-patient groups (e.g., Jahanshahi et al., 1995; Kurtzberg & Vaughan, 1982) have reported different patterns of brain activity involved in these two types of actions. In initiated movements, there is more extensive activity in pre-SMA areas, and this activity starts earlier (Cunnington, Windischberger, Deecke, & Moser, 2002; Deiber, Honda, Ibanez, Sadato, & Hallett, 1999). These findings have been complemented by research into voluntary movements showing that initiated movements are preceded by extensive pre-SMA activity, whereas reactive movements are not (Libet, Wright, & Gleason, 1982, 1983; Soon, Brass, Heinze, & Haynes, 2008). However, this research only indicates that the planning phase is different in the two cases; this does not resolve our research question of whether the execution of reactive actions is faster than the execution of initiated actions.

A number of studies have measured the time to execute reactive and initiated actions (e.g., Cunnington et al., 2002; François-Brosseau et al., 2009; Jenkins, Jahanshahi, Jueptner, Passingham, & Brooks, 2000). François-Brosseau et al. (2009) and Jenkins et al. (2000) reported that the execution of reactive actions was slower than the execution of initiated actions, whereas Cunnington et al. (2002) reported a small, but non-significant advantage for reactive actions. However, none of these studies was actually designed to test which type of action could be performed more quickly. Participants were not instructed to execute the required motions as quickly as possible. Rather, the procedure would be that participants, for instance, would perform a sequence of button-presses at their own pace in the initiated condition, in the reactive condition external cues (beeps or flashes) would be provided at the same pace as in the initiated condition, and participants would try to follow the lead of the external cues as closely as possible. Thus, these studies do not serve as tests of Bohr's hypothesis.

Recently, Welchman, Stanley, Schomers, Miall, and Bülthoff (2010) directly tested Bohr's hypothesis by having subjects participate in a mock shoot-out. They started a 'gun duel' by resting one hand on one of the three buttons. To pull and shoot a gun the subject lifted her hand from this button and, with the same hand, pushed the two other buttons in succession. Their goal was to win the gun duel. Subjects were instructed to vary the moment of action initiation. Furthermore they saw whether their opponent had started their action. Thus, sometimes they would act in response to their opponent's move, and sometimes they would act of their own accord. In accordance with Bohr's hypothesis, motion execution was faster when subjects reacted to an opponent than when they initiated the duel. However, this speed benefit came at a cost, since subjects made more errors when reacting than when acting. Welchman et al. characterized this as "fast and dirty" processing.

The goal of this paper was to determine if and when reactions are faster than actions. We set out to replicate the Welchman et al. (2010) findings and then to determine the boundary conditions on the effect. Our first question was to determine whether the reactive advantage necessarily entailed "fast and dirty" processing (i.e., a speed-error tradeoff). If we could obtain a reactive speed advantage without a significant error cost, then this might implicate qualitatively different motor processes, as suggested by the neural data cited above. On the other hand, if reactions can only be executed more quickly than self-initiated actions at the cost of more errors, this would be more easily explained as a threshold shift.

Our second question was whether the reactive advantage generalizes beyond very simple actions. Welchman et al. (2010) had subjects perform two-step actions. However, the bulk of their effect happened during the first step. Therefore we investigated both one-step and two-step actions, to find out whether only the simplest of motions yields faster reactions, or if this holds more generally. For example, would having to choose from several options make a difference? Initiated actions create more activity in SMA and pre-SMA areas, which seem to be involved in choosing between different options (Isoda & Hikosaka, 2007; Soon et al., 2008). Thus, we hypothesize reactive actions are faster when only a single action is possible, while initiated actions will have the advantage when there is a choice of actions.

We examined how quickly initiated and reactive actions are executed in three experiments. First we replicated Welchman et al.'s (2010) results by having subjects participate in a mock shoot-out. However, we stressed that overall reaction times were not important. We found that this manipulation eliminated the accuracy difference between reacting and acting, while replicating the finding that reacting is faster than acting. In Experiment 2 we removed the shoot-out setting, and had participants performing either one-step or two-step actions. We found that when people perform one-step tasks, reactive movements are executed faster than initiated movements. With two-step motions, however, this effect disappeared. In Experiment 3, participants had to choose between two alternatives. This manipulation reversed the effect, such that participants were faster in executing an initiated action than a reactive action.

The current experiments support Niels Bohr's psychophysical intuition, while placing limits on its generalizability. Reactive actions are faster than initiated actions, but only for simple ballistic actions.

Experiment 1: Gunfight at the RT corral

Experiment 1 was similar to the Welchman et al. (2010) design, with some critical differences. Participants were told that they would perform a small number of duels in a "shoot-out" game against the computer, getting visual feedback on each duel in terms of their successfully shooting their opponent. However, while Welchman et al. used a two-step action, we asked our participants to perform a one-step action. Moreover, participants were told that only movement time mattered, and that overall reaction time was not important. We expected that these instructions would reduce any speed-accuracy trade offs.

Apparatus and stimuli

Stimuli in all experiments were presented on a 20-inch monitor set to a resolution of 1,024 by 768 at a refresh rate of 75 Hz, controlled by a Macintosh G5 computer running Mac OS 10.4. The experiment was programmed in Matlab 7.5 (The MathWorks) using the Psychophysics Toolbox routines (Brainard, 1997; Pelli, 1997). Participants were seated approximately 57.4 cm from the monitor; at this distance, 1 cm on the screen subtends one degree of visual angle (°).

Method

In Experiment 1 participants always performed a very simple action. They started each trial by resting one finger of their dominant hand on the 5-button of the numlock pad. At some point they had to lift this finger of the 5-button and press the 4-button, as quickly as possible. This action was framed as a "shoot-out." A cartoon drawing of a cowboy facing them would appear on the screen, face on (see Fig. 1), and participants' task would be to either shoot whenever they wanted to (the *villain* condition), or respond upon seeing their opponent draw his gun (the *hero* condition; the opponent drew his gun at a randomly selected moment between 500 and 4,000 ms after the start of the trial). After each trial they received graphical feedback as to whether they had won or lost: if they won they would see an opponent with a red blob on his shirt; if they lost they would see an unfazed cowboy with a smoking gun. So in the *villain* condition, a participant would always see a cowboy with a drawn, smoking gun (this would be the trigger to act). If they performed the action quickly enough, this picture would be replaced by the picture of a cowboy with a red stain on his shirt. In the *hero* condition they would see the picture of a cowboy staring at them, and after the execution of their action they would either see a cowboy with a smoking gun or a cowboy with a red-stained shirt. Winning was based on whether their inter-button time (IBT, in ms) was faster than a randomly picked number between 50 and 100. Twenty-four naïve volunteers between the ages of 18 and 22 (average age 19.54 years) participated. Each participant performed 2 practice trials (one act and one react trial), followed by 5 act trials and 5 react trials or vice versa (counterbalanced across participants). Importantly, the action participants had to perform was a one-step, forced-choice action (i.e., they released the 5-button and pressed the 4-button as quickly as possible after release).

The dependent measure of interest throughout this paper is the time it takes to execute an action, the IBT.

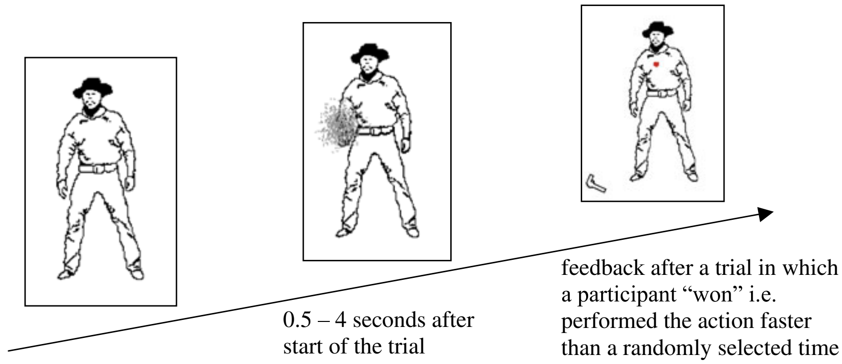
Note that the game setting (the shoot-out frame) was intended only to make the task fun for participants. No participant reported any psychological problems with performing the task or seeing the pictures. The study was approved by the IRB of Harvard University.

Results and discussion

On approximately 7.5% of the trials in the react condition, participants started performing the motion before or while the trigger appeared. These trials were excluded from the analysis. Furthermore, trials in which participants were slower than 400 ms were also removed from the analysis, resulting in a further loss of approximately 1.7% of trials (we did not apply relative filtering here, since standard deviations become meaningless if you only have 5 trials per condition per subject; we therefore applied an absolute filter for removing the outliers).

Errors were defined as trials on which the participant pushed the wrong button. Thus, in this and the other experiments, only when a wrong button was pushed, this

Fig. 1 A cartoon drawing of a cowboy appeared on the screen, face on, and participants' task would be to either shoot whenever they wanted to (the *villain* condition) or respond upon seeing their opponent draw his gun (the *hero* condition)



was considered as an error (since outliers and reactive trials in which participants self-initiated their action were excluded from the analysis). See Fig. 2 for an overview of the error results and the Inter-Button Time (IBT) results. As expected, replicating the Welchman et al. (2010) results, participants were considerably faster in the react condition than in the act condition ($t(23) > 2.7$, $p = 0.01$, $\eta^2 = .242$), as shown in the left panel of Fig. 2. Were these "fast and dirty" responses? We defined errors as trials on which the participant pushed the wrong button. Error rates are shown in the right panel of Fig. 2. There was no significant difference in errors ($t(23) < 0.5$, $p > 0.65$, $\eta^2 = .007$), and the trend was for slightly more errors in the act condition, following the IBT results. This indicates that our instructions worked to eliminate the speed-error tradeoff.

More importantly, the data demonstrate that it is possible to obtain a reactive advantage without a speed-error tradeoff. This supports Bohr's hypothesis that reactive actions are executed reliably faster than initiated actions.

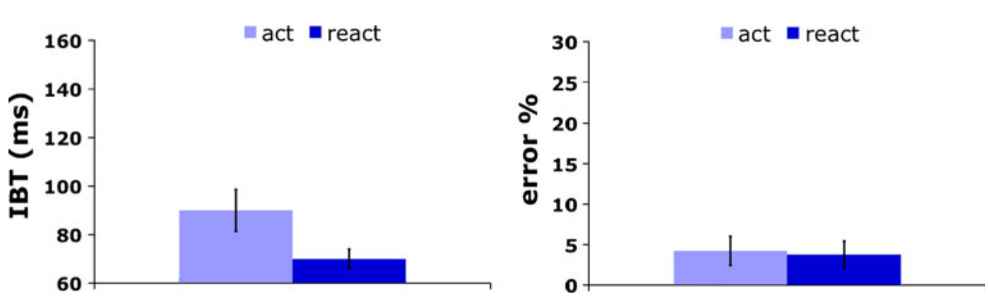
Experiment 2: A react advantage for one-step but not two-step actions

In Experiment 1 we found that for very simple actions, reactive actions are indeed executed faster than initiated actions. In Experiment 2 we removed the "shoot-out" setting, to investigate whether this framing plays a critical role. Furthermore, we added a two-step condition [similar to that used in Welchman et al. (2010)], allowing us to study the effects of action complexity on the reactive advantage.

Method

Ten naïve volunteers between the ages of 22–49 (average 32.6 years) participated. The experiment consisted of 6 blocks of 30 trials and took approximately 10 min. Participants started each trial with one finger holding down the 5-key of the numlock pad. The *one-step* action was to lift this finger from the 5-key and press the 4-key as quickly as possible. The *two-step* action was to lift the finger from the 5-key and then press the 4-key and the 7-key in succession. Participants were only permitted to use one finger for the experiment. Participants were instructed to carry out the movements as quickly and accurately as possible. They were specifically instructed that we were only interested in inter-button time. Reactive versus initiated actions were varied across blocks. Each trial started with the participant holding down the 5-key, at which point the screen turned black until the participant performed the instructed action. In the *act* blocks, participants could release the 5-key and start the sequence of button-release and button-press(es) whenever they wanted. In the *react* blocks, participants were instructed to start the sequence in response to the trigger: a briefly flashed white disk, presented at a randomly selected moment between 500 and 4,000 ms after the start of the trial. The 0.4° diameter disk (CIE: x,y: 0.284, 0.3210 luminance: 51.95 cd/m^2) was presented at the center of the screen for 13 ms (i.e., a single monitor refresh). The one-step action

Fig. 2 Overview of the error results and the Inter-Button Time (IBT) results



was run in the first four blocks, and the two-step action in the last two blocks. Blocks alternated between act and react blocks, with the order counterbalanced across participants.

Results

The first half of the first block was for practice, and these trials were excluded from the analysis. On approximately 1% of the react trials, participants released the key before or while the trigger was presented. These trials were also not considered in the analysis. Trials with IBTs more than 3 standard deviations away from the mean (per participant, per condition) were also excluded from analysis. This resulted in the exclusion of 0.55% of the trials.

See Fig. 3 for an overview of the IBT and error results. A planned comparison between the act and the react condition for both types of motion revealed that participants were significantly faster in executing the motion when they were reacting rather than acting for one-step actions ($t(9) = 2.27$, $p < 0.05$, $\eta^2 = .364$), but not two-step actions ($t(9) < 0.5$, $p > 0.75$, $\eta^2 = .01$). Furthermore, participants were significantly faster in performing the first step of the two-step actions when they were reacting ($t(9) = 2.47$, $p < 0.05$, $\eta^2 = .403$), but there was no difference in execution speed for the second step ($t(9) = 0.82$, $p > 0.4$, $\eta^2 = .07$). Note that the total time for executing the two-step action is the sum of the IBTs for the first step and the second step plus the resting time after the first and before the second action (resting times did not differ significantly, $t(9) = 1.43$, $p > 0.15$, $\eta^2 = .184$).

For the one-step actions, the trend was towards a speed-accuracy tradeoff, though the difference between act and react conditions was not significant ($t(9) = 1.65$, $p = 0.13$, $\eta^2 = .232$). Errors in the two-step condition followed the overall IBTs, though again the difference was not significant ($t(9) = 1.71$, $p = 0.12$, $\eta^2 = .247$). Note that although there is no significant difference between resting times and second step, these tend to be somewhat faster in the act than in the react condition, which explains why the speed advantage for the reactive movements is not observed for the two-step actions.

Discussion

With one-step actions, we again replicated the reactive advantage. However, this advantage for reacting only held for the first step of a two-step action. Why might this be? One possibility is that the execution of the second step becomes more similar across conditions. For example, the second step might be triggered by the first step, making it functionally an initiated action, independently of the trigger for the first step. This would serve to reduce the difference between the two conditions. If we look at the IBTs for the two steps separately, the IBTs for the first step closely resemble those for the one-step case, with a 25-ms reactive advantage. For the second step, both conditions yield IBTs that are equivalent to the IBT for the one-step initiated condition. In other words, when an action is comprised of multiple actions, it seems that only the first action shows a reactive speed advantage; the other actions are equally fast for both reactive and initiated actions. Thus, the overall reactive speed advantage should decrease as more steps are added.

Note that Welchman et al. (2010) did find a significant speed advantage for reactive movements, even with two-step actions. Their experiment may simply have been more sensitive. Additionally, the speed-accuracy tradeoff may have increased the size of the IBT advantage in their experiment, whereas our data did not show a speed-accuracy tradeoff for two-step actions.

Importantly, we find that framing the task as a shoot-out does not affect the speed benefit for reactive actions (although IBTs were faster overall in Experiment 1 than in Experiment 2, 80 vs. 113 ms., $t(32) = 2.74$, $p < 0.01$, $\eta^2 = .1053$; there was no significant difference in reactive speed advantage, $t(32) = 1.02$, $p > 0.3$, $\eta^2 = .016$).

Thus, it seems to be a fundamental feature of the motor system that simple actions are carried out faster when they are performed in response to an external trigger. Why should this be the case? As we noted in the introduction, several studies have shown that reactive actions generate less activity in SMA and pre-SMA areas than initiated

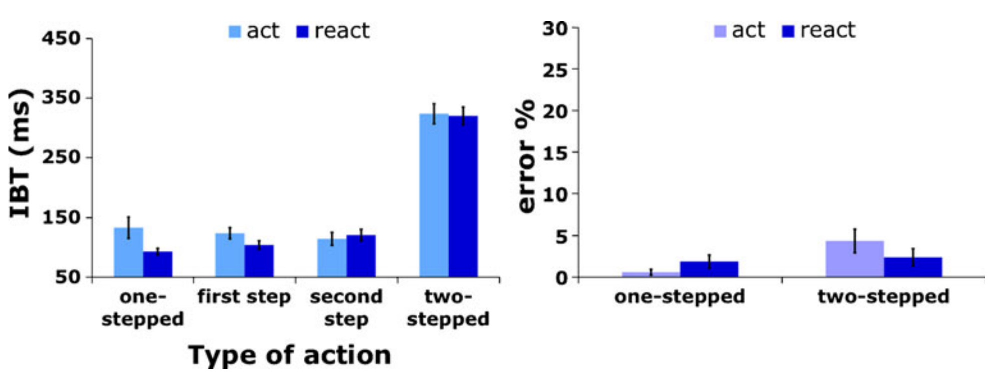


Fig. 3 Overview of the IBT and error results

actions. One highly speculative way to interpret these data would be to suggest that during initiative actions, the motor system is in some sense "overthinking." For example, some studies suggest that SMA and pre-SMA areas are essential for switching between different options (e.g., Isoda & Hikosaka, 2007; Rushworth, Hadland, Pans, & Sipila, 2002). If the pre-SMA is involved in selecting among several courses of action (e.g., Soon et al., 2008), then perhaps the additional SMA activity is simply unnecessary for the ballistic actions we have been studying.

To return to the gunslinger motif, reacting might be faster than acting in a standard shootout, when you face a single adversary, but if an innocent barmaid strays into the scene and you have to be sure to choose the correct target, it might be better to be the villain and initiate your own shot. In the next experiment, we tested the hypothesis that the reactive advantage would be eliminated in a choice task.

Experiment 3: An initiated advantage for two-alternative actions

Experiment 3 was essentially the same as Experiment 2, except that instead of always having to do one action (i.e., releasing the 5-button followed by pressing the 4-button), participants had to perform one of two possible one-step actions. After releasing the 5-button they would either have to press the 4-button or the 6-button. Participants again either acted of their own accord or reacted to an external trigger. This trigger could be a flash on the left side of the screen or the right side of the screen. In addition to comparing acting to reacting, within the react condition we added the manipulation of congruency. That is, a flash on the left could either indicate that the 5-button had to be released and the button to the left had to be pressed (i.e., the 4-button: the congruent condition), or a flash on the left could mean that the button to the right of the 5-button had to be pressed (the incongruent condition).

If reactive actions are faster than initiated actions in general, then we should again find that reactive actions are executed faster than initiated actions. However, we hypothesize that reactive actions are less flexible than initiated actions, and therefore IBTs in the reactive condition should be slower. Furthermore, since reactive actions are inflexible, incongruent actions should suffer especially, yielding the highest IBT times in the react incongruent condition.

Method

Everything was the same as in Experiment 2, except for the following changes. Six new, naïve participants between the ages of 20 and 51 (average age 31.0 years) performed 3 blocks of 32 trials. There were three types of blocks: act, react congruent, and react incongruent. The order of the blocks was counterbalanced across participants. In all cases a trial started by the participant resting one finger on the 5-button of the numlock pad. In the act condition, the participant released the 5-button and pressed either the 4-button or the 6-button. Participants were instructed to vary both the moment of initiation of the action and the choice they would make. In both the react congruent and the react incongruent condition, at a randomly chosen moment, 0.5 - 4 s after the start of the trial, a white flash would appear either 0.8° to the left or to the right of the middle of the screen (the flash was a white circle with a diameter of 0.8°). In the react congruent condition a flash on the left triggered the participant to release the 5-button and press the 4-button, whereas a flash on the right triggered the participant to release the 5-button and press the 6-button. In the react incongruent condition, a flash on the left required pressing the 6-button and a flash on the right required pressing the 4-button. Participants were instructed that their only objective was to carry out the movement as quickly as possible.

Results and discussion

See Fig. 4 for an overview of the IBT results and the error rates. Reactive trials in which participants released the 5-button before or while the trigger appeared were removed from analysis, resulting in a loss of approximately 6.5% of reactive trials. Furthermore, IBTs more than 3 standard deviations away from the mean were excluded from analysis, resulting in the loss of an additional 3.0% of trials (thus in total 7.3% of all trials were excluded).

When we collapse the two reactive conditions, we find that participants were faster in executing initiated actions

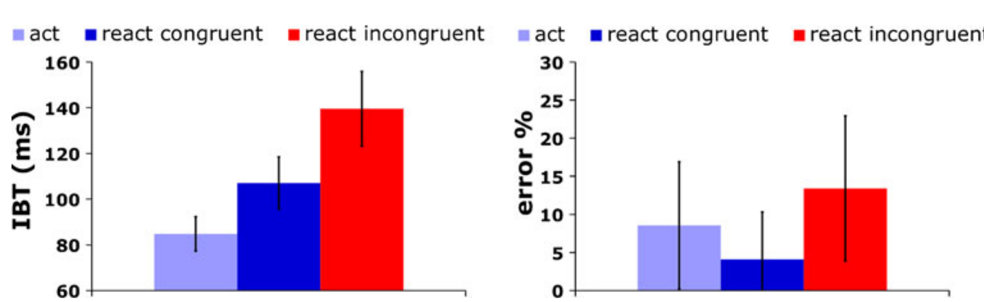


Fig. 4 Overview of the IBT results and the error rates

than in executing reactive actions ($t(5) = 5.03$, $p < 0.005$, $\eta^2 = .835$). Furthermore, IBTs in the react congruent condition were significantly faster than IBTs in the react incongruent condition ($t(5) = 3.7$, $p = 0.01$, $\eta^2 = .732$). Again, collapsing across reactive condition, we found that there was no significant difference in errors between initiated and reactive movements ($t(5) < 0.05$, $p > 0.95$, $\eta^2 = .000$). However, participants did make significantly more errors in the react incongruent condition than in the react congruent condition ($t(5) = 3.8$, $p < 0.015$, $\eta^2 = .744$). Since this error pattern reflects the IBT pattern, speed-accuracy tradeoffs can be excluded.

Experiment 3 is consistent with the notion that reactive actions fare best in a rigid setting. Just adding a second option makes reactive actions slower than initiated actions. Furthermore, when the to-be-carried-out action is incongruent with the trigger (i.e., the trigger is on the left, the action is to the right), reactive actions become even slower.

These findings fit our hypothesis that reactive actions are qualitatively different from initiated actions and are especially suited for 'ballistic' actions. The current findings also put obvious constraints on the generalizability of the speed benefit for reactive actions. This speed benefit only occurs in very specific situations, i.e., when the action is simple and there are no alternatives that need to be considered.

General discussion

Our findings bear out Bohr's hypothesis that reacting is faster than acting. We replicate and extend the Welchman et al. (2010) result that people are faster at performing a speeded motor action when it is externally triggered than when it is self-initiated. Importantly, we have also placed some boundary conditions on "Bohr's law." The react advantage is limited to the first step of a complex action and is reversed if the participant actually has to make a choice.

As we noted in the introduction, intuition would suggest that initiated actions should be faster, since we should only initiate them when we have entirely finalized all necessary planning, while an external trigger might catch us at an inopportune stage of motor planning. So how can we explain the counter-intuitive benefit in speed for reactive over initiated actions? We argue that initiated actions involve more conscious reflection or planning, possibly involving feedback loops with higher brain areas, whereas reactive actions might be more "ballistic." Under this interpretation, the widespread activation in the brain during initiated actions might reflect a loss of focused activation in the motor areas, relative to reactive actions (Cunnington et al., 2002; Deiber et al., 1999; Jahanshahi et al., 1995; Kurtzberg & Vaughan, 1982; Libet et al., 1982, 1983; Soon et al., 2008). The results of Experiment 3 of the current study, where we found that the speed benefit for reactive actions vanished when a choice of actions was introduced, support this account.

This hypothesis, in turn, makes predictions for neurophysiological experiments. It suggests that the increased activity observed for initiated, willed actions in SMA and pre-SMA should be accompanied by reduced activation in purely motor-related areas. This notion could be directly tested using existing neuroimaging techniques. Given a one-step, ballistic action with no choice involved, we should observe a dissociation between sensorimotor and motor areas as a function of initiated versus reactive actions.

At any rate, the current study suggests that reactive and initiated actions are qualitatively different types of actions. It is not that reactive motions are initiated motions with a criterion shift (where one strategically trades accuracy for speed), rather reactive motions and initiated motions have different characteristics. Although the final output is the same, initiated motions are more deliberate, which makes them slower, but more flexible. Reactive motions are more ballistic, which makes them faster and more rigid. The notion that initiated and reactive movements are qualitatively different is supported by the work of Obhi and Haggard (2004). They examined reaction times, and recorded EMG activity in the right first dorsal interosseous, while subjects performed either a self-initiated or a reactive motion. In the critical condition they had subjects start with an initiated action, and then switch to a reactive action. This caused a relatively long delay in reaction times (more than 50 ms), suggesting a switch between operating mode, rather than adjusting an action within one mode. Moreover, the unique EMG signatures of initiated and reactive actions were preserved, again suggesting that the motor system switched from one mode to another.

To further elucidate the difference between reactive and initiated actions, it would also be interesting so see how far the react advantage can generalize. We have shown that when participants have to choose between two actions, acting becomes faster. What if participants have to choose between a single action and not acting (e.g., shoot the gunman, but not the unarmed bystander)? Will fatigue exacerbate or diminish it?

Conclusions

As Niels Bohr hypothesized several decades ago, externally triggered actions are indeed executed faster than self-initiated actions. The Hollywood cliché of the hero who always manages to outgun the villain, despite the apparent handicap of shooting second, has a grain of truth to it. The good guy will always win if he just has to pull the trigger, but he'd better have his safety off first, and hope that there is only one bad guy.

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References

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10* (4), 433–436.

Cunnington, R., Windischberger, C., Deecke, L., & Moser, E. (2002). The preparation and execution of self-initiated and externally-triggered movement: A study of event-related fMRI. *Neuroimage, 15*, 373–385.

Deiber, M. P., Honda, M., Ibanez, V., Sadato, N., & Hallett, M. (1999). Mesial motor areas in self-initiated versus externally triggered movements examined with fMRI: Effect of movement type and rate. *Journal of Neurophysiology, 81*, 3065–3077.

François-Brosseau, F. E., Martinu, K., Strafella, A. P., Petrides, M., Simard, F., & Monchi, O. (2009). Basal ganglia and frontal involvement in self-generated and externally-triggered finger movements in the dominant and non-dominant hand. *European Journal of Neuroscience, 29*, 1277–1286.

Gamow, G. (1988). *The great physicists from Galileo to Einstein. Chapter: The law of quantum* (p. 238). Dover: Mineola.

Isoda, M., & Hikosaka, O. (2007). Switching from automatic to controlled action by monkey medial frontal cortex. *Nature Neuroscience, 10*, 240–248.

Jahanshahi, M., Jenkins, I. H., Brown, R. G., Marsden, C. D., Passingham, R. E., & Brooks, D. J. (1995). Self-initiated versus externally triggered movements: I. An investigation using measurement of regional cerebral blood flow with PET and movement-related potentials in normal and Parkinson's disease subjects. *Brain, 118*, 913–933.

Jenkins, I. H., Jahanshahi, M., Jueptner, M., Passingham, R. E., & Brooks, D. J. (2000). Self-initiated versus externally triggered movements II. The effect of movement predictability on regional cerebral blood flow. *Brain, 123*, 1216–1228.

Kurtzberg, D., & Vaughan, H. G. (1982). Topographic analysis of human cortical potentials preceding self-initiated and visually triggered saccades. *Brain Research, 243*, 1–9.

Libet, B., Wright, E. W., & Gleason, C. A. (1982). Readiness-potentials preceding unrestricted spontaneous vs pre-planned voluntary acts. *Electroencephalography and Clinical Neurophysiology, 54*, 322–335.

Obhi, S. S., & Haggard, P. (2004). Internally generated and externally triggered actions are phyiscally distinct and independently controlled. *Experimental Brain Research, 156*, 518–523.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10* (4), 437–442.

Rushworth, M. F. S., Hadland, K. A., Paus, T., & Sipila, P. K. (2002). Role of the human medial frontal cortex in task switching: A combined fMRI and TMS study. *Journal of Neurophysiology, 87*, 2577–2592.

Siegert, R. J., Harper, D. N., Cameron, F. B., & Abernethy, D. (2002). Self-initiated versus externally cued reaction times in Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology, 24*, 146–153.

Soon, C. S., Brass, M., Heinze, H. J., & Haynes, J. D. (2008). Unconscious determinants of free decisions in the human brain. *Nature Neuroscience, 11*, 543–545.

Welchman, A. E., Stanley, J., Schomers, M. R., Miall, R. C., & Bülthoff, H. H. (2010). The quick and the dead: When reaction beats intention. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 277*, 1667–1674.