

Race to accumulate evidence for few and many saccade alternatives: an exception to speed–accuracy trade-off

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Abstract Hick’s law states that increasing the number of response alternatives increases reaction time. Lawrence and colleagues report an exception to the law, whereby more alternatives lead to shorter saccadic reaction times (SRTs). Usher and McClelland (Psychol Rev 108(3):550–592. doi:10.1037/0033-295X.108.3.550, 2001) predict such an anti-Hick’s effect when accuracy is not prioritized in a task, which should result in higher error rates with more response alternatives, and in turn to a shorter right tail of the SRT distribution. In the current study, we aim to replicate the original controversial findings and we compare them to these predictions by examining error rates and SRT distributions. Two experiments were conducted where participants made rapid eye movements to one of few or many alternatives. In Experiment 1, the saccade target was an onset and participants started either with few or many possible target locations and then alternated between conditions. An anti-Hick’s effect emerged only when participants had started with a small set-size block. In Experiment 2, placeholders were displayed at the possible target locations and independent groups were used. A reliable anti-Hick’s effect in SRTs was observed. However, results did not meet the stated predictions: anticipations and false direction errors were never more frequent when the set size was larger and SRT differences between the two set-size

conditions were not more pronounced at the slower end of the distributions. In line with Lawrence and colleagues, we speculate that initial motor preparation, and the subsequent inhibition to counteract a premature response, may induce the anti-Hick’s effect.

Keywords Decision-making · Saccades · Movement planning · Trade-offs · Saccade distribution

Introduction

In typical choice reaction time tasks, a predominant finding is that reaction times increase linearly with the logarithm of the number of response alternatives, a regularity known as Hick’s law (Hick 1952; Hyman 1953). From early on, Hick’s law has been modelled with different computational approaches. A more recent example comes from Usher and colleagues (Usher and McClelland 2001; Usher et al. 2002) who developed an accumulator model, simulating the time it takes to reach a decision by assuming several competing units, each accumulating sensory evidence for one of the different response alternatives. A decision is ultimately made when activity in one of the units “wins the race” by reaching a threshold, leading to the execution of the corresponding motor response. Because accumulation is also driven by sensory noise and its rate is variable, sometimes the wrong accumulator unit reaches threshold first, leading to a premature, incorrect response. With a larger set size, that is, a larger number of incorrect response alternatives in the competition, the likelihood that one of those beats the correct response alternative to threshold is higher than with fewer response alternatives. Usher et al. (2001, 2002) suggested that Hick’s law may be explained by a strategic raise in threshold with more response alternatives to counter this

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higher risk for error. If the response threshold is raised, the likelihood that the correct accumulator unit wins the race increases, as on a longer time scale, the accumulation of target evidence should eventually exceed any accumulation of noise. This increase in threshold comes at the expense of reaction time, though. In other words, Usher et al. (2001, 2002) postulate that Hick's law is the result of a simple speed–accuracy trade-off and participants' effort to maintain error rates at a constantly low level across set-size conditions.

Although generally a robust finding, violations of Hick's law have also been reported in the literature. For instance, in a series of studies, Lawrence and colleagues (Lawrence et al. 2008; Lawrence 2010; Lawrence and Weaver 2011) measured eye movement reaction times in both monkeys and humans in an easy target selection task. Gaze was initially maintained on a central fixation stimulus that was surrounded by placeholders, one of which became the saccade target. Across blocks, they varied set size, that is, the number of saccadic response alternatives by varying the number of initial placeholders. Contrary to Hick's law, they found *faster* saccadic reaction times (SRT) with larger set sizes, an observation they termed an anti-Hick's effect. Experiments without placeholders were also conducted, where only the number of possible locations for the saccade target was varied across blocks, giving the same results. The authors tentatively framed their findings in terms of inhibition acting on initial motor preparation. When there are only few response alternatives, all of them are strongly pre-activated. However, while waiting for the saccade target to be revealed, inhibitory mechanisms are engaged to preclude premature execution of a saccade. Overcoming this inhibition comes at the cost of longer SRTs. Instead, when there are many possible target locations, there is less or no motor preparation of the different response alternatives in the first place, leading to weaker or no inhibition, and in turn to faster SRTs.

Interestingly, Usher and McClelland (2001; p 582) describe an alternative, purely stochastic explanation of how anti-Hick's effects may occur. They note that in one of their tested computational models, faster reaction times with more response alternatives are to be expected when the same threshold criterion is used across set-size conditions. As indicated above, similar thresholds should lead to more errors with larger set sizes as the likelihood that one of the incorrect response alternatives wins the race to threshold increases. However, it also follows that there should be fewer trials at the slow end of the RT distribution for correct trials: if target evidence accumulates slowly on a given trial (potentially leading to a slow, but correct response when only few response alternatives are present), the likelihood that one of the incorrect response alternatives reaches threshold prematurely is higher than when target

evidence accumulates fast. Those trials, instead of becoming correct trials with long RTs, will thus more often end up as error trials, in particular, false direction and/or anticipation trials. Consequently, mean RTs on correct trials will be overall *faster* with increasing set size. In sum, Usher and McClelland's (2001) simple race model explanation makes very specific predictions for anti-Hick's effects: higher error rates with larger set sizes, along with a decreasing proportion of slower responses in the RT distribution for correct responses.

Our goal in the current study was twofold: our first aim was to replicate Lawrence and colleagues' (Lawrence et al. 2008; Lawrence 2010; Lawrence and Weaver 2011) anti-Hick's effect which, so far and to our knowledge, has not been confirmed in the literature by other laboratories. Second, we further explore error rates, specifically anticipation and false direction errors (Experiments 1 and 2) and reaction time distributions (Experiment 2) across set-size conditions to see whether the predictions of Usher and McClelland's (2001) simple stochastic explanation could explain the anti-Hick's effect or whether a more complex explanation, for instance in terms of inhibition, may be needed.

Experiment 1

Following the design of Lawrence et al. (2008), we compared blocks with two versus six saccadic response alternatives in a within-subjects design in Experiment 1.

Methods

Participants

Eighteen students from the University of Geneva, ranging between 18 and 33 years of age, were tested in the experiment. All were naïve as to the motives of the study. The experiments were undertaken with the understanding and written consent of all participants and were carried out in accordance with the Declaration of Helsinki and approved by the departmental ethics committee.

Apparatus

The experiment was written in MATLAB 2011b (The MathWorks Inc., Natick, MA) using the Psychophysics and EyeLink Toolbox extensions (Cornelissen et al. 2002; Kleiner et al. 2007) and run on a Dell Optiplex 755 system. The stimuli were displayed on a 21" CRT monitor (NEC MultiSync FE2111SB), which ran on 85 Hz and was set to 1280 × 1024 pixels and viewing distance was 70 cm. The EyeLink 1000 desk-mounted eye tracker was used to record eye movements (SR Research Ltd., Mississauga, Ontario,

Canada) at a sampling rate of 1000 Hz. Participants were seated in a dimly lit room and placed their heads within a fixed chin and forehead rest. Movements from the right eye were recorded for all participants bar one, whose left eye was recorded.

Stimuli

Displayed on a dark grey background (5 cd/m^2), the fixation stimulus was an open grey circle (14 cd/m^2) of 1.5° radius (pen width 0.33°), while the saccade target was a red circle (8 cd/m^2) of the same size at an eccentricity of 10° eccentricity from the centre of the screen.

Design and procedure

Figure 1 illustrates the sequence of events in Experiment 1. Participants were instructed to maintain gaze on the central grey circle for 350 ms. After this fixation period, the red saccade target circle appeared abruptly at one of either two or six possible locations (blocked), requiring participants to move their gaze as fast and accurately as possible towards it. Within a block of trials, the target appeared at each possible location with equal probability. Preliminary analysis of eye movement data was carried out after each trial and a feedback screen indicated anticipations, breaks of fixation, saccades in the wrong direction or if no saccade was detected (see below for criteria). At the end of a trial, the participant pressed the spacebar to commence a new trial. All participants took part in both set-size conditions, performing three blocks of 60 trials in each (360 trials total). One group of participants started with a block with two possible target locations; another started with a block with six possible target locations. Both groups proceeded by alternating between set-size conditions across blocks.

Results

Trial exclusion

To ensure that any differences we observed were due to set-size effects and not affected by different saccade directions, we first excluded all trials from the larger set-size condition where the saccade target was presented at a location other than the two locations also used in the small set-size conditions. That is, only trials were analysed in which the target was presented on the horizontal meridian, either left or right from fixation (180 trials in the small set size and 60 trials in the large set size). From those, another 8.7% of trials were excluded either because the saccade starting point deviated more than 1.5° from the centre of the screen (break of fixation), the saccade landed more than 5° from

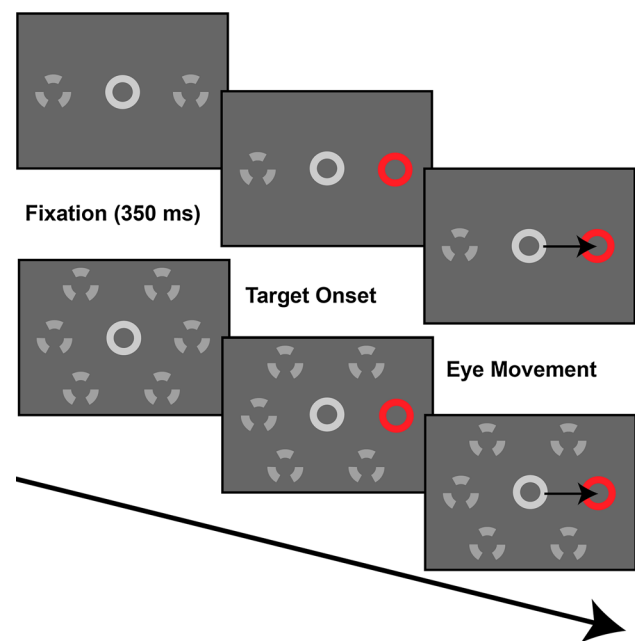


Fig. 1 Procedure in Experiment 1. The central *light grey circle* is the fixation stimulus, and the *dashed grey circles* denote locations where the saccade target could appear (not visible during the experiment). In *red* is depicted the saccade target (circle to the right in the example), which appeared unpredictably in any of the two or six locations within a block of trials (color figure online)

the centre of the saccade target and the SRT was above 500 ms or because of technical issues.

Trials were marked as anticipations if latency was below 80 ms. False direction errors were defined as trials in which the saccade's direction deviated more than 30° away from the direction of the target. Anticipations and false direction trials were excluded from the SRT comparisons, but analysed separately (see "[Anticipations and false direction trials](#)" section).

Saccadic reaction times

Median SRTs for correct trials are illustrated in Fig. 2. A $2 \times 3 \times 2$ mixed ANOVA was performed, with two levels for set size (two vs. six possible target locations; within subjects), three levels for block (first, second or third block within a given condition; within subjects) and two levels for order, to see whether performance was affected by beginning the task with a block of two versus six response alternatives (between subjects). Neither the main effect of set size, $F(1,16) = 0.54$, $p = .474$, nor the main effect of order, $F(1,16) = 0.05$, $p = .828$, were significant. There was a significant main effect of block number, $F(2,32) = 3.30$, $p = .050$, partial $\eta^2 = .171$, and a marginally significant interaction between set size and order also emerged, $F(1,16) = 3.65$, $p = .074$, partial $\eta^2 = .186$. None of the other two-way interactions were significant,

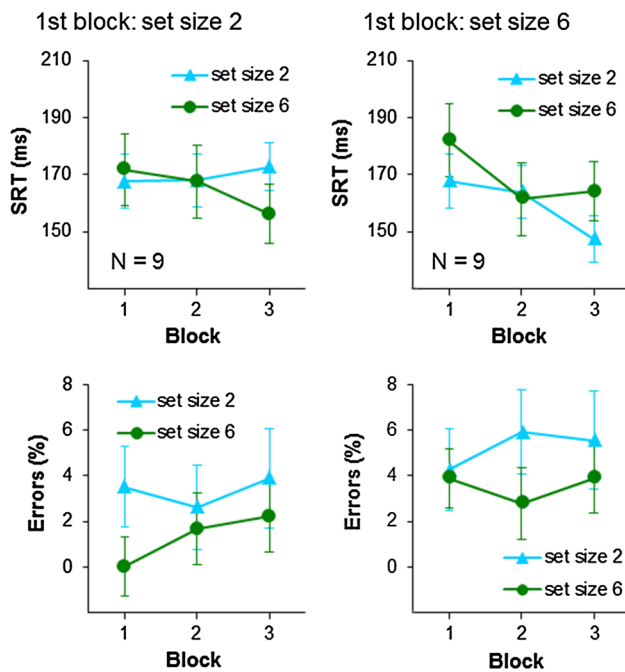


Fig. 2 Results of Experiment 1. The different columns compare the data (saccadic reaction times on correct trials and percentage of errors: anticipations and false direction) across the two participant groups starting with two (*left column*) or six (*right column*) response alternatives. Set-size conditions (*blue two, green six*) are compared for each of these groups across the duration of the experiment (first, second or third block within each set-size condition). Error bars standard error of the means (color figure online)

$F_s < 1.59$, $p_s > .219$. Figure 2 illustrates that the data pattern is best-described by the significant three-way interaction, $F(2,32) = 3.91$, $p = .030$, partial $\eta^2 = .196$.

Following up on this interaction, separate ANOVAs for the two participant groups revealed that for participants starting with two response alternatives (left graph in Fig. 2), there were no significant main effects, $F_s < 0.82$, $p_s > .392$, but a significant two-way interaction between set size and block, $F(2,16) = 3.62$, $p = .050$, partial $\eta^2 = .312$. Post hoc tests indicated there was no statistical difference between set-size conditions in the first or second block, $t_s(8) < 0.50$, $p_s > .634$. However, the third time a participant was presented with a block of two or six possible target locations; a significant difference in SRTs favouring the six possible target condition was observed, $t(8) = 2.43$, $p = .041$. This comparison was the only occurrence of an anti-Hick's effect in the data of Experiment 1, and it suggests that the anti-Hick's effect had built up slowly across trials, at least in one group of observers. In contrast, Lawrence et al. (2008, 2010, 2011) never observed an effect of training. Experiment 3 performed by Lawrence et al. (2008) bears the strongest resemblance to the current experiment and was carried out on six participants, which were a mix of

students and university employees, one of whom was an author. Perhaps a likely familiarity with the task could have counteracted any effect of training in their experiment.

In contrast, for the participant group starting with six response alternatives, no significant interaction was observed, $F(2,16) = 2.18$, $p = .145$, and there was also no significant main effect of set size, $F(1,8) = 3.03$, $p = .120$, but only a significant main effect of block, $F(2,16) = 6.31$, $p = .010$, partial $\eta^2 = .441$, indicating a general speed-up of responses across blocks.

In sum, we could only partially replicate Lawrence and colleagues' (Lawrence et al. 2008; Lawrence and Weaver 2011; Lawrence 2010) anti-Hick's effect: we observed faster reaction times with a larger set size only when participants had started with a small set-size block, and even then the difference only developed at the end of the experiment, that is, when comparing the last pair of blocks. Note also, however, that we did not observe any reliable Hick's-like pattern, which is longer SRTs with a larger number of response alternatives in any of our comparisons. Although Fig. 2 shows slightly faster SRTs with two versus six response alternatives in the first and third block for the group starting with set size six, these differences were not sufficiently reliable to result in any significant effects or interactions.

Anticipations and false direction trials

Figure 2 (lower panels) illustrates the percentage of anticipations and false direction trials across conditions. Equivalent to the SRT analysis, we conducted a $2 \times 3 \times 2$ mixed ANOVA, including the factors set size, block and order. Only a significant main effect of set size was observed, $F(1,16) = 6.00$, $p = .026$, partial $\eta^2 = .273$, indicating a higher rate of anticipations and direction errors with the smaller set size. No further effect or interaction approached significance, $F_s < 1.36$, $p_s > .272$. Thus, error rates did not mirror the SRT results as Usher & McClelland's account in terms of a speed-accuracy trade-off predicted.

Experiment 2

In Experiment 1, we observed an anti-Hick's effect only when participants had started with a small set-size block. It has been shown that the way a motor task is initially approached may affect subsequent conditions (e.g. see Tandonnet et al. 2014). Therefore, using a within-subjects design and alternating set-size blocks may not have been ideal to obtain a strong effect, despite Lawrence and colleagues reporting the anti-Hick's effect even in a within-subjects design. In Experiment 2, we therefore employed a between-subjects design with two set-size groups.

Methods

In total, 30 participants were tested in Experiment 2 with age ranging from 18 to 35 years. Apparatus and stimuli remained as in Experiment 1 with the following exceptions: placeholders of the same size, colour and luminance as the fixation stimulus were displayed from the beginning of a trial at each of the possible saccade target locations. This made the eye movement locations immediately obvious, possibly allowing to bypass the training period observed in Experiment 1. A between-subjects design was employed, where each participant carried out only three blocks with either two or six response alternatives. Gaze was to be initially maintained on the central fixation stimulus for 800–1200 ms, after which one of the placeholders turned red to mark the saccade target.

Results

Trial exclusion

Again, only trials with targets presented on the horizontal meridian were kept for analysis. From those, another 12.7% of trials were excluded due to breaks of fixation, saccade amplitude errors, late or missed saccades, or technical issues (see “[Trial exclusion](#)” section for criteria).

Saccadic reaction times

Figure 3 illustrates the results of Experiment 2. A 3×2 mixed ANOVA was carried out, where block was the within-subjects factor with three levels and set size the between-subjects factor with two levels. There was a significant main effect of block, $F(2,56) = 3.68$, $p = .031$, partial $\eta^2 = .116$, reflecting an overall speeding up of responses across blocks, and a significant main effect of set size, $F(1,28) = 4.88$, $p = .036$, partial $\eta^2 = .148$. Figure 3a

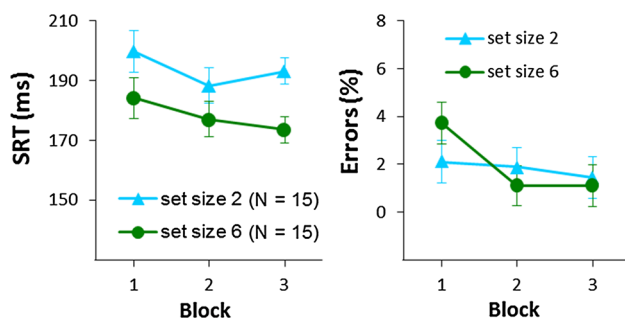


Fig. 3 Results of Experiment 2. Saccadic reaction times on correct trials (*left*) and error percentages (anticipations and false direction trials, *right*) in the grouped set-size conditions (*blue* two, *green* six) are compared across the three blocks of the experiment. Error bars standard error of the means (color figure online)

illustrates that this effect was due to an anti-Hick's pattern: SRTs were faster with the larger set size. The interaction was not significant, $F(2,56) = 0.59$, $p = .559$.

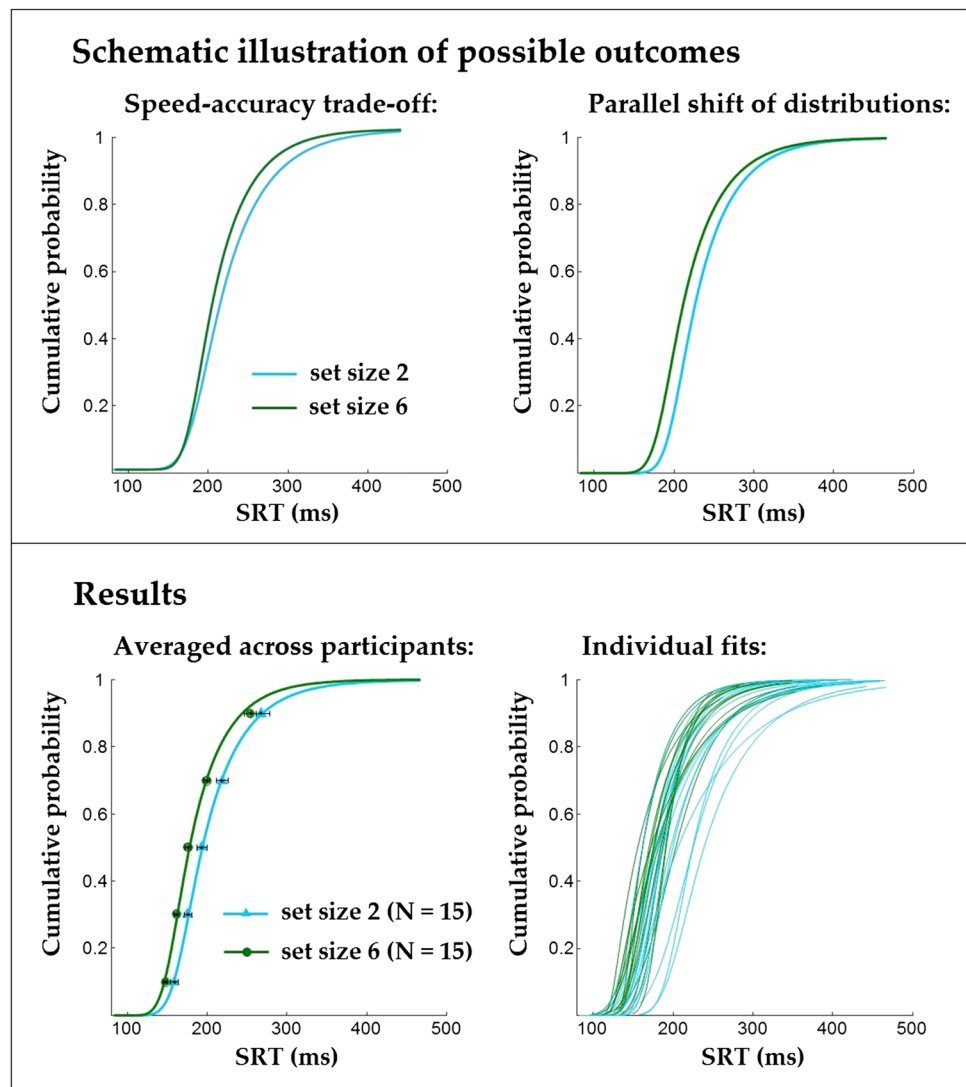
Error trials

An ANOVA equivalent to the SRT analysis on the percentage of anticipations and false direction trials only revealed a marginally significant main effect of block, $F(2,56) = 2.99$, $p = .058$, partial $\eta^2 = .096$, reflecting a slightly decreasing error rate across blocks. The main effect of set size, $F(1,28) = 0.04$, $p = .847$, and the interaction, $F(2,56) = 1.53$, $p = .225$, did not approach significance. Thus, similar to Experiment 1, the error rates did not mirror the SRT results. More specifically, the anti-Hick's effect in SRTs was not accompanied by a higher error rate for the larger compared to the smaller set size.

SRT distributions

As we obtained a stable anti-Hick's effect in all three blocks of Experiment 2, we were able to also explore SRT distributions for correct trials. According to a speed-accuracy trade-off explanation in an accumulator model framework, differences between set-size conditions should be more pronounced at the slow end of the distributions: for slow accumulation of target evidence, the probability that an incorrect response alternative reaches threshold before the target is higher with larger set sizes; thus, the distribution of correct trials should contain fewer trials with long SRTs than the small set-size distribution (see Fig. 4, upper left). Alternatively, the entire distribution may be shifted towards longer SRTs in the small set-size condition (see Fig. 4, upper right for illustration). To test these predictions, we first collapsed SRTs of all blocks for each participant and we calculated percentiles, comparing the 10, 30, 50, 70, and 90% cut-off of the individual distributions. Triangle and circle symbols in Fig. 4 (lower left) illustrate the mean cut-off points across participants in the two groups. For all percentiles, the cut-offs in the larger set-size group were reached at faster SRTs. A 2×5 mixed ANOVA including the factors set size (between subjects) and percentile (within subjects) revealed a trivial main effect of percentile on the SRTs, $F(4,112) = 268.40$, $p < .001$, partial $\eta^2 = .906$, but also a significant main effect of set size, $F(1,28) = 4.75$, $p = .038$, partial $\eta^2 = .145$. The interaction was not significant, $F(4,112) = 0.37$, $p = .831$, indicating that faster SRTs in the larger set-size condition were not restricted or more pronounced at the slow end of the distributions, as might have been expected from the predictions of a speed-accuracy trade-off. This was further confirmed in an additional analysis for which we fitted ex-Gaussian distributions (using MATLAB toolboxes from

Fig. 4 SRT distributions in Experiment 2. *Upper panels* predictions. A speed–accuracy trade-off predicts a right-shifted (larger μ), as well as less steep (larger σ and τ) cumulative probability function for the smaller set size (*left*). To the right an example of a parallel shift of the distribution (larger μ , but equal σ and τ parameters in the small set-size condition). *Below results*. To the left the mean cut-off points for the 10, 30, 50, 70 and 90% percentiles (circles and triangles) and cumulative ex-Gaussian functions based on the average μ , σ and τ parameters for each grouped set-size condition (blue two, green six). To the right the cumulative ex-Gaussian fitted to the data of each of the 30 participants (see also Supplementary Figure S1) (color figure online)



Lacouture and Cousineau 2008, and Zandbelt 2014) to the data of each participant (see Fig. 4, lower right and Supplementary Figure S1), and then compared the average mean (μ), standard deviation (σ), and exponential component (τ , skewness) across the two groups (corresponding functions resulting from the average parameter values across participants in each group are illustrated in Fig. 4, bottom left). The average μ parameters of the fitted distributions showed a marginally significant difference between the two groups (set size 2: $\mu = 159$ ms, set size 6: $\mu = 147$ ms), $t(28) = 1.90$, $p = .068$, indicating that the distributions in the larger set-size condition were slightly shifted towards faster SRTs. In contrast, the standard deviation and skewness parameters σ and τ did not differ significantly (set size 2: $\sigma = 15.55$, $\tau = 46.51$, set size 6: $\sigma = 13.58$, $\tau = 41.14$), $t_s(28) < 1.05$, $p_s > .302$, confirming a similar shape of the distributions across groups, that is, a largely parallel shift of the two distributions. Note also that although the curves

based on the average parameters (Fig. 4, lower left) seem to differ slightly more at the slower end, this was also the range where the fits deviated most from the percentiles (at least for set size 6).

General discussion

In two experiments, we aimed at replicating the anti-Hick's effect, that is to say, a speeding up of saccadic reaction times when faced with a larger number of response alternatives, as reported by Lawrence and colleagues (Lawrence et al. 2008; Lawrence 2010; Lawrence and Weaver 2011). We further explored whether the effect could be explained by a simple speed–accuracy trade-off as proposed in the context of an accumulator race model (Usher and McClelland 2001). Employing a within-subjects design without placeholders (Experiment 1), we only found an anti-Hick's

effect in the last block of the participant group starting with a small set size block. In contrast, with a between-subjects design with placeholders (Experiment 2), we found a reliable anti-Hick's effect in SRTs. However, anticipations and false direction errors were never more frequent in the larger set-size condition and a distribution analysis for correct trials showed that the SRT differences in the two set-size conditions were not restricted to, or more pronounced at, the slower end of the distributions. Thus, although Usher and McClelland's (2001) speed–accuracy trade-off account offers an appealing and simple explanation for the potential occurrence of anti-Hick's effects, our results were not in line with its predictions and we conclude that a more complex explanation might be needed to explain the effect under the present conditions.

We see that the anti-Hick's observation is reproducible, although it remained somewhat fragile in Experiment 1 and only emerged robustly in Experiment 2. As it was present already in the first blocks of Experiment 2, training in the task may in the end not have been needed (as we had presumed after the results of Experiment 1). We suspect the anti-Hick's effect emerged in Experiment 2 due to a greater emphasis on motor preparation (and potential subsequent inhibition; see below). Recall that in contrast to Experiment 1, all potential target objects were visible from the beginning of the trial (making it possible to reinforce motor preparation by visual guidance), while the fixation duration until the target was revealed was longer. Thus, potentially prepared saccades needed to be withheld for longer to avoid anticipations and false direction errors. However, while these procedural differences could play a role, it remains unclear why, for instance, Lawrence et al. (2008) found a robust anti-Hick's effect with a procedure very similar to our Experiment 1.

In other paradigms, having to act upon, or decide between, fewer stimuli almost ubiquitously lead to shorter reaction times (Hick's effect). Even though different modelling approaches have been used, the basic idea of a speed–accuracy trade-off similar to the proposal by Usher and McClelland (2001) underlies the Hick's effect in most. For instance, Brown et al. (2009) assume a constant error rate across set sizes in their Bayesian model (although they mention that this was in fact not what they observed in their data). Churchland and Ditterich (2012) argue that when the number of response alternatives is increased, the level of uncertainty is also increased, requiring the brain to accumulate more evidence before the decision is reached; in other words, they assume a raise in threshold. Note that an increase in threshold is equivalent to a lower starting point for evidence accumulation in accumulator models: both change the distance between starting point and threshold and thus affect the time until threshold is reached equally. It has been suggested that different starting points reflect

the prior probability of a decision alternative (e.g. Carpenter and Williams 1995). Accordingly, when neuronal firing rates in structures like the lateral intraparietal area or the superior colliculus were compared in a task where monkeys had to make saccades to either one of few or many alternatives, higher firing rates were observed for the few alternatives task, particularly at the initial preparatory stage before the actual target had been revealed (Basso and Wurtz 1997, 1998; Churchland et al. 2008). Thus, when the possible motor alternatives are few, movements are prepared and the accumulation of activation begins closer to threshold; when instead the alternatives are many, it is potentially too costly to compute all of them; therefore, little or no preparation takes place.

Given these observations, it seems reasonable that an explanation of the anti-Hick's effect should be centred on the small set-size condition, as few response alternatives have been seen to increase brain activity and that their well-documented advantage did not take place in our study. In the accumulator framework, one may again presume a raised threshold or lowered starting point in the few alternatives condition to counteract premature saccades due to too much motor preparation. Importantly, error rates may thereby not further decrease as they are already very low in the first place, as there is only one non-target response alternative towards which saccades could be falsely directed (see Fig. 3).

The critical point is that Usher and McClelland (2001) suggestion implies that performance in the few alternatives remains relatively fixed across conditions that lead to Hick's or anti-Hick's effects and it is performance in the many alternative condition that can be modulated (based on error rate). In contrast, we think it is likely that performance for many alternatives, where preparation is minimal or non-existent, remains stable across conditions that induce a Hick's or anti-Hick's effect. The anti-Hick's effect may therefore not result from an increased urgency in the many alternative condition. On the other hand, it would appear that performance is modulated, possibly based on motor preparation, when the alternatives are few. Support for this notion comes from Lawrence and Weaver (2011). They measured SRTs to two or six possible targets, comparing a condition in which set size was blocked to a condition where set size was randomly interleaved from trial to trial. Only the blocked condition showed an anti-Hick's effect. The effect resulted from slower responses with set size two in the blocked compared to the mixed condition, whereas responses with set size six remained constantly fast across conditions. In sum, few saccade alternatives may produce Hick's effect in conditions with strong motor preparation (not evident in our study; but see e.g. Rolfs and Vitu 2007, Experiment 3) or anti-Hick's effects if motor preparation has to be thwarted to avoid premature responses. The

maximum set size to produce these modulations could be two or three: for Hick's as well as anti-Hick's effects, the largest SRT differences were found when increasing set size from two to four (Lawrence et al. 2008; Rolfs and Vitu 2007).

Lawrence and colleagues (Lawrence et al. 2008; Lawrence 2010; Lawrence and Weaver 2011) suggested that the inhibition may arise at the level of the superior colliculus. Alternatively, it has been shown that when hand or wrist movements are being prepared the corticospinal pathway is highly involved in activating inhibitory components which assure execution is not triggered prematurely (for a review see Cohen et al. 2010). This has been identified as an inhibitory mechanism for voluntary movement, and the key notion here is that the movement must be temporarily inhibited while our senses continue to process and accumulate external information: a process that is linked to the planning of movements when the set size is small and that has a detrimental effect on movement initiation. It was recently shown by Wessel et al. (2013) that suppressing saccades reduced corticospinal excitability of hand movements. This constituted strong evidence that suppression of saccadic eye movements can produce global motor effects (see also Cai et al. 2012; Majid et al. 2012). In line with Cohen et al.'s (2010) notion of motor inhibition emerging at the planning phase (the authors refer to it as "global inhibition"), perhaps planning eye movements while in settings requiring high levels of motor control is sufficient to activate these inhibitory components, which could be related to anti-Hick's effects. A study found increased activity in the subthalamic nucleus of the basal ganglia, an area with direct connections to the corticospinal pathway, in saccade-countermanding and NoGo tasks (Isoda and Hikosaka 2008). There is therefore support for the view that high levels of control during eye movement preparation are achieved thanks to activity in the corticospinal pathway, which is common to other limb movements. This activity temporarily inhibits movements and may be the process that is added to the otherwise beneficial preparation seen for small set sizes. However, the involvement of global inhibition in the anti-Hick's effect is highly speculative. For instance, the observation that anti-Hick's effects seem to be restricted to exogenous saccades casts some doubts on our global inhibition hypothesis: Lawrence (2010) reports that there is no anti-Hick's effect for endogenous saccades. Also, it does not emerge in reaction times for reaches when accompanied by exogenous saccades that show an anti-Hick's pattern in SRTs (Lawrence and Gardella 2009).

In conclusion, the current study provides evidence for the controversial finding that a larger number of alternatives can reliably lead to reduced SRTs. By comparing error rates and saccadic distributions, it became clear that the predictions made by Usher and McClelland (2001)

based on a speed–accuracy trade-off could not account for our findings. We believe that a process such as global inhibition that can become activated during the movement planning phase could be a candidate to account for the findings, particularly in conditions requiring high control and a strong stimulus–response pairing. Future investigations will be needed to determine whether other limb movements or cognitive activity are temporarily suppressed in instances when the anti-Hick's effect emerges and to map out its neurophysiological underpinnings.

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