Does sensitivity in binary choice tasks depend on response modality?

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ABSTRACT

In most models of vision, a stimulus is processed in a series of dedicated visual areas, leading to categorization of this stimulus, and possible decision, which subsequently may be mapped onto a motor-response. In these models, stimulus processing is thought to be independent of the response modality. However, in theories of event coding, common coding, and sensorimotor contingency, stimuli may be very specifically mapped onto certain motor-responses. Here, we compared performance in a shape localization task and used three different response modalities: manual, saccadic, and verbal. Meta-contrast masking was employed at various inter-stimulus intervals (ISI) to manipulate target visibility. Although we found major differences in reaction times for the three response modalities, accuracy remained at the same level for each response modality (and all ISIs). Our results support the view that stimulus-response (S-R) associations exist only for specific instances, such as reflexes or skills, but not for arbitrary S-R pairings.

1. Introduction

The very same stimuli can be mapped on very different motor responses, such as manual button presses, eye movements, or verbal responses. For example, when observers are asked to discriminate a square vs. a diamond, responses can be verbal “left”/“right” expressions, left/right button presses, or left/right eye movements. Most models assume, implicitly or explicitly, that stimuli are first processed in a sensory stage (e.g., photo-transduction at the retina), followed by a series of visual processing stages, leading to representation and categorization of the stimulus (Donders, 1969; Hubel & Wiesel, 1959; Marr, 1982; Poggio, 1984; Sternberg, 1969). Based on the categorization, a decision is made, and executed as a motor-response. Processing is fully independent of the type of the motor-response. Hence, accuracy for given stimuli and tasks is also independent of the type of the motor-response (as long as motor execution errors do not differ across response modalities).

In sharp contrast to these theories, sensori-motor contingency theories propose that certain stimuli may be specifically mapped onto certain motor-responses. For example, a skill like riding a bike comes with distinct sensori-motor contingencies. Similar to the Gibsonian approach (Gibson, 1966), the theory of event coding proposes that stimuli are coded by joint visuo-motor representations (e.g., Hommel & Müsseler, 2001). In the spirit of the behavioristic tradition, sometimes mental
representations are entirely abandoned and identified with motor-actions (Nagel, Carl, Kringe, Martin, & König, 2005; O’Ragan & Noé, 2001). In such models, accuracy may differ for the same stimulus when motor responses are different. For example, for certain stimuli, eye movements may be the more “appropriate” motor-action than verbal responses, leading to superior performance (e.g., Hughes & Kelsey, 1984). Motor (e.g., saccadic) responses are faster than verbal response. They can be more automatic and may even be triggered by unconsciously perceived features. In line with this idea, performance in a near-threshold flash detection task was shown to be better when observers made a saccade than when they pressed a button (Hughes & Kelsey, 1984).

Accuracy may also strongly differ when stimuli are processed along different pathways, associated with different motor responses. For example, it is often assumed that a stimulus is processed both in the “conscious” ventral stream, specialized in shape and color analysis, and in the “unconscious” dorsal stream, being specialized in motor functions (Goodale, 2014; Goodale & Milner, 1992; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). Both streams may be differently sensitive to specific stimulus features. Indeed, patients with hemianopia are still able to make a saccade or to point to a target, but they cannot verbally report about this stimulus (Marcel, 1983; Perenin & Jeannerod, 1975; Poppel, Held, & Frost, 1973).

Experiments on motor priming also suggest that there are transient task dependent stimulus-response mappings (Jaśkowski, van der Lubbe, Schlotterbeck, & Verleger, 2002; Jaśkowski, Skalska, & Verleger, 2003; Klotz & Neumann, 1999, etc.). In these studies, a prime stimulus (e.g., a rectangle on one side and a diamond on the other side) is followed by a slightly larger stimulus pair containing the target. Observers indicate the side on which the target (rectangle or diamond) was presented. Visibility of the prime increases when the ISI increases. Both with invisible and with visible primes, manual responses are commonly faster when the relevant shapes of the prime and the target are on the same side (i.e., congruent) as compared to when they occur on different sides (i.e., incongruent). This effect is commonly denoted as the priming effect and is often understood as being the consequence of activation of the corresponding motor response (e.g., see Klotz & Neumann, 1999). In line with the latter idea, other studies revealed that presentation of a prime already induced hand motor activation (e.g., Jaśkowski et al., 2002, 2003; Klotz, Heumann, Ansorge, & Neumann, 2007). Moreover, invisible primes may not only modulate responses to subsequent targets but may even elicit a wrong response (Jaśkowski et al., 2003). Subliminal priming effects were not limited to hand motor reactions as they also facilitated verbal responses (Ansorge, Klotz, & Neumann, 1998; Eimer & Schlaghecken, 2001). Thus, motor priming is not limited to a specific response modality.

Here, we asked the question whether accuracy in a visual binary choice task depends on response modality.

2. General method

2.1. Participants

In total, 14 participants (ten males, four females; aged 18–28; mean 23.8) recruited from the local student population in Lausanne took part in the experiments (four in Exp. 1 and ten in Exp. 2). Participants were paid 20 CHF per hour. All observers had normal or corrected-to-normal visual acuity as determined by a computerized visual acuity test (Freiburg Visual Acuity Test; Bach, 1996). To participate in the experiment, participants had to reach a value of 1.0 (corresponding to a Snellen fraction of 20/20) for at least one eye. The experiment was conducted with the informed and written consent of each participant. All procedures complied with the Declaration of Helsinki and were approved by the local ethics committee.

2.2. Apparatus

Stimuli were presented on a Philips 201B4 CRT monitor driven by a standard accelerated graphic card refreshed at 75 Hz (Exp. 1) or on an ASUS VG248QE LCD monitor with 120 Hz refreshed rate (Exp. 2). Participants were seated in a room dimly illuminated by a background light of about 0.5 lx. The observation distance was 90 cm. Participants were restrained by a chinrest. For eye movement control, we used the iView X-HiSpeed eye tracker from SensoMotoric Instruments (SMI), which was set up for binocular mode with a 500 Hz sampling frequency. Signals of both eyes were averaged in order to reduce noise. Verbal responses were registered by a Hama Stereo Directional Microphone (RMZ-14).

2.3. Stimuli and procedure

Trials started with a fixation dot presented for 1 s. Subsequently, a square was presented for 13 ms (Exp. 1) or 17 ms (Exp. 2) pseudo-randomly either to the left or right from the central fixation dot at 4° of eccentricity. A diamond was simultaneously presented at the opposite side (Fig. 1). The square and diamond had an equal width of 0.8°. After a variable ISI, a mask was presented at the square and diamond location for 100 ms. The inner masks contours abutted the contours of the square and diamond. The mask size was 1° × 1°. All stimuli were black outlines and were presented on a gray background (Exp. 1: 18 cd/m², Exp. 2: 52 cd/m²).

Half of the participants were instructed to indicate as accurately as possible whether the square was on the left or on the right side, while the other half of the participants had to indicate the side of the diamond. In three different sessions, responses were given with either the left or the right hand, by making a saccade to the left or right, or with verbal responses by saying “left” or “right”. A trial ended after the participant’s response or after a maximal time interval of 5 s. The order of
2.4. Data analysis

Trials with premature (<50 ms) and late (>1500 ms) responses were discarded and repeated within the same block (<0.5%). Saccade direction was determined online. The eye had to land within a circular window with a radius of 3° centered on the target. The verbal responses were recorded by microphone and they were classified (for left and right responses) by the experimenter offline. RTs were computed using MATLAB software.

Participants' responses per response modality were averaged for each ISI. For each condition, we determined a psychometric function on the basis of the distribution of the proportion of correct responses as a function of the ISI. Thus, we had nine conditions (3 response modalities × 3 days) for each individual. As shown in previous studies (Albrecht, Klapötke, & Mattler, 2010; Francis & Herzog, 2004; Maksimov, Murd, & Bachmann, 2011) the shape of metacontrast masking could be either S-shaped (a so-called Type A masking, where performance increases as a function of ISI) or U-shaped (a Type B masking, good performance for short and long ISIs; Kolers, 1962). Since masking shape might vary between participants and we were mainly interested in the performance increase which occurs for medium ISIs, data for all ISIs except the shortest ISI (0 ms) from each participant and condition were fitted with a sigmoidal logistic S-shaped function. We determined the ISI for which a threshold of 75% correct was reached, and we also determined the slope of the psychometric functions. The threshold allows us to compare performance in the localization of the masked stimulus (lower threshold means higher sensitivity for the masked stimuli). The slope can provide information about the accumulation of the information (e.g., shallower slope may reflect an increase in the range of ISIs for which performance in localization task is better). The advantage using estimated parameters is that the noise per ISI can be reduced. The lapse rate parameter (the probability of an incorrect response which is independent of stimulus intensity) was set at 0.01 in Exp. 1. In Exp. 2, raw results were corrected before determining psychometric function, thus, the lapse rate parameter was set at 0. The goodness of fit of the psychometric function was determined using the method log-likelihood estimation as described in Wichmann and Hill (2001) through the Palamedes routines for MATLAB (Kingdom & Prins, 2010; Neggers, Schölvinck, van der Lubbe, & Postma, 2005).

The threshold and the slope for each participant, each response modality (manual, saccadic, verbal) and each testing day (first, second, third) were calculated and statistically analyzed with a 3 × 3 repeated measures ANOVA. In addition, we analyzed accuracy for each ISI and each response modality (manual, saccadic, verbal) across the examination days in a 12 × 3 repeated measures ANOVA. When necessary, degrees of freedom were corrected with Greenhouse-Geisser ε coefficients.

To corroborate our possible null results, we complemented the traditional null hypothesis testing by a more informative Bayesian analysis (Wagenmakers, 2007). We computed the Bayesian Information Criterion (BIC) which indicates the probability $p_{BIC}(H_0|D)$ that the null hypothesis is true for the available set of data D. We followed the procedure advocated by Masson (2011; see also Wagenmakers, 2007).
3. Experiment 1

The major aim of Experiment 1 was to explore whether thresholds and slopes differ as a function of response modality. If sensori-motor contingencies are involved, manual and saccadic responses may be privileged, thus, a lower threshold and possibly also a steeper slope for motor responses is predicted than in the case of verbal responses. Furthermore, perceptual learning might be limited to specific S-R links, thus, effects of testing day may also be restricted to the conditions with a certain response modality.

3.1. Results and discussion

We found a main effect of ISI on the percentage of correct responses (PC; Fig. 2A; \(F(11,33) = 29.63, p < 0.001, \eta^2 = 0.91\)). The PC increased from 56% for the shortest ISI (0 ms) to 97% for the longest ISI (147 ms). There was no main effect of response modality \(F(2,6) = 0.70, p = 0.48, \eta^2 = 0.19\). All three masking functions did only slightly differ from each other (Fig. 2A). Most importantly, there was no significant interaction between response modality and ISI \(F(22,66) = 0.86, p = 0.48, \eta^2 = 0.22\).

Response times (RT) decreased with increasing ISI from 1044 ms for an ISI of 0 ms to 770 ms for an ISI of 147 ms \(F(11,33) = 9.57, p < 0.001, \eta^2 = 0.76\). RTs differed between the response modalities \(F(2,6) = 23.33, p = 0.001, \eta^2 = 0.89\); Fig. 2B). RTs were significantly longer for verbal than for manual responses (1438 vs. 667 ms, \(t(3) = 5.17, p = 0.014\)) and saccades (1438 vs. 537 ms, \(t(3) = 4.82, p = 0.017\)). RTs for manual responses and saccades did not differ significantly from each other (667 vs. 537 ms, \(t(3) = 2.1, p = 0.13\)). The interaction between ISI and response modalities was significant \(F(22,66) = 3.13, p < 0.001, \eta^2 = 0.51\). Reaction time decreased with ISI but only for verbal responses \(F(1,3) = 14.48, p < 0.05, \eta^2 = 0.83\).

![Fig. 2. Results of Experiment 1. A. Percentage of correct responses as a function of ISI for the three response modalities. No significant differences were observed between the different response modalities. B. RTs were significantly longer for verbal than for saccadic and manual responses. There was no significant difference between manual and saccadic response times. Response Times decreased with increasing ISIs for each response modality. Error bars indicate the standard error of the mean for 4 observers.](image1)

![Fig. 3. Experiment 1. ISI for which a threshold of 75% correct was reached for each day and each modality. The threshold was higher on the second day than on the third day. Error bars indicate the standard error of the mean for 4 observers.](image2)
The threshold of the psychometric function did not depend on response modality (Fig. 3; F(2,6) = 1.16, p = 0.37, $\eta^2 = 0.28$, $p(H_0|D) = 0.75$). The main effect of testing day on the threshold was significant (F(2,6) = 6.14, p = 0.035, $\eta^2 = 0.67$, $p(H_0|D) = 0.05$). The ISI for which a threshold of 75% correct was reached, was shorter on the third day than on the second testing day (t(3) = 3.82, p = 0.03, $p(H_0|D) = 0.03$). There was no significant interaction between response modality and testing day (F(4,12) = 0.93, p = 0.44, $\eta^2 = 0.24$, $p(H_0|D) = 0.96$). The slope of the psychometric function also did not depend on response modality (F(2,6) = 0.39, $p = 0.72$, $p(H_0|D) = 0.72$), nor on the testing day (F(2,6) = 1.06, $p = 0.38$, $\eta^2 = 0.26$, $p(H_0|D) = 0.70$). No significant interaction was observed between response modality and testing day (F(4,12) = 1.11, p = 0.37, $\eta^2 = 0.27$, $p(H_0|D) = 0.95$). All non-significant results were examined with Bayesian analyses, which revealed a high probability of the null hypothesis being true. Psychometric functions for each participant and goodness of fit values are available in the Supplementary Materials.

Experiment 1 revealed that location discrimination depended on ISI, however, no difference was found of the required response modality. These findings suggest that visual processing is independent from response modality, in line with classic models. An interesting outcome of Experiment 1 concerns the influence of testing day on the thresholds, which, however, did not differ as a function of response modality. Thus, perceptual learning seems to be involved in line with previous reports (Hernandez & Lefton, 1977; Hogben & Di Lollo, 1984; Schwiedrzik, Singer, & Melloni, 2009). As the same effect was found for all response modalities, our results do not support the idea that perceptual learning occurs for specific S-R links only.

4. Experiment 2

Although faster reaction times were observed for manual and saccadic responses as compared to verbal responses, it is possible that responses were not fast enough to benefit from specific S-R links. Therefore, a nearly identical experiment was carried out with speeded responses.

4.1. Methods

Methods and instructions were the same as in Experiment 1, except for the explicit instruction to respond as fast and as accurately as possible. The duration of the stimuli and ISIs were slightly different due to the use of a different screen (see General Method). One block consisted of 130 randomized trials (12 ISIs x 10 repetitions). The experiment was again conducted over 3 days with 12 blocks per day (4 blocks for each response modality). In total there were 4680 trials for each participant.

4.2. Results and discussion

We observed a main effect of ISI (Fig. 4A; F(11,99) = 110.517, p < 0.001, $\eta^2 = 0.92$). PC increased from 58% for the shortest ISI (0 ms) to 93% for the longest ISI (150 ms). There was a main effect of response modality (F(2,18) = 17.198, p < 0.001, $\eta^2 = 0.66$). Performance was significantly worse for saccadic responses than for manual (73% vs 78%, t(6) = 2.64, p < 0.05) and verbal responses (73% vs 79%, t(6) = 3.12, p < 0.05). The interaction between response modality and ISI was also significant (F(22,198) = 2.701, p < 0.001, $\eta^2 = 0.23$). More errors were made in the case of saccadic responses than in case of manual and verbal responses, at least when ISIs were longer than 42 ms.

Response time (RT) did not depend on ISI (F(11,99) = 1.82, p = 0.06, $\eta^2 = 0.17$). RTs differed between response modalities (F(2,18) = 97.43, p < 0.001, $\eta^2 = 0.91$; Fig. 4B). RTs were significantly longer for verbal than for manual responses (803 vs. 432 ms, t(9) = 6.096, p < 0.001). The interaction between ISI and response modalities was significant (F(22,198) = 1.79, p = 0.02, $\eta^2 = 0.17$). RT decreases with ISI but only for verbal responses (F(11,99) = 2.36, p = 0.01, $\eta^2 = 0.21$).

In contrast with Experiment 1, we observed lower performance levels for saccades than for manual and verbal responses in Experiment 2. Since this lower performance occurs even for well visible stimuli (e.g. ISI = 150 ms), it seems that saccadic responses were more affected by lapses than manual and verbal responses. To correct for these differences, performance was modified by using the following equation:

$$P' = PC + (1 - PC)(P - PC)$$

$$\frac{(PC - PL)}{PL}$$

where $P'$ is the probability of correct responses for a certain ISI, $P$ is the probability of correct responses including lapses and constant errors, $PC$ is the chance level of 0.5 and $PL$ is the lapse rate determined as the probability of an incorrect response for the ISI of 150.

After correction for differences in lapse rates (Fig. 4C), there is no longer a significant interaction (F(22,198) = 1.276, p = 0.19, $\eta^2 = 0.12$). The main effect of ISI was significant (F(11,99) = 112.938, p < 0.001, $\eta^2 = 0.93$). The main effect of response modality was also significant (F(2,18) = 4.583, $p = 0.025$, $\eta^2 = 0.34$). Overall, performance was slightly worse for saccadic responses than for manual responses (78% vs 80%, t(9) = 2.721, p = 0.024).

\footnote{1 $P(H_0|D)$ - the probability of the null hypothesis being true for the available set of data D. Strength of the evidence: 0.50–0.75: weak, 0.75–0.95: positive, 0.95–0.99: strong, >0.99 very strong (Raftery, 1995).}
The threshold of the psychometric function did not depend on response modality (Fig. 5; \(F(2,18) = 2.46, p = 0.11, \eta^2 = 0.21, p(H_0|D) = 0.64\)). The main effect of testing day on the threshold was significant (\(F(2,18) = 25.97, p < 0.001, \eta^2 = 0.74, p(H_0|D) < 0.01\)). The ISI, at which a threshold of 75% correct was reached, was longer on the first day than on the second (75 vs. 56 ms, \(t(9) = 6.89, p < 0.001, p(H_0|D) < 0.01\)) and the third testing day (75 vs 53 ms, \(t(9) = 7.81, p < 0.001, p(H_0|D) < 0.01\)). The interaction between the effect of different response modalities and testing day on the threshold was significant (\(F(4,36) = 2.79, p = 0.04, \eta^2 = 0.24, p(H_0|D) = 0.12\)). The threshold for saccadic response was larger than for manual response (84 vs 66 ms, \(t(9) = 3.56, p = 0.006, p(H_0|D) = 0.05\)) but only on the first testing day. The slope of the psychometric function did not depend on the response modality (\(F(2,18) = 0.032, p = 0.65, \eta^2 = 0.034, p(H_0|D) = 0.93\)) nor did the testing day (\(F(2,18) = 0.28, p = 0.64, \eta^2 = 0.031, p(H_0|D) = 0.94\)). The interaction between response modality and the testing day was also not significant (\(F(4,36) = 0.79, p = 0.47, \eta^2 = 0.08, p(H_0|D) = 0.99\)). All non-significant results were also confirmed by Bayesian analyses. They revealed for these effects that there is a high probability of the null hypothesis being true.

Fig. 4. Results of Experiment 2. A. Accuracy as a function of ISI for the three response modalities. Accuracy for saccadic responses was lower than for manual and verbal responses. B. RTs changed with ISI only for verbal responses. RTs were significantly longer for verbal than for manual responses which were significantly longer than saccades. C. Corrected accuracy as a function of ISI for the three response modalities. Saccadic responses were shorter than manual and verbal responses. Error bars indicate the standard error of the mean for 10 observers.

Fig. 5. Experiment 2. ISI at which a threshold of 75% correct was reached for each day and each modality. Threshold was larger on the first day than on the second and the third day. Threshold for saccadic response was larger than for manual response but only on the first testing day. Error bars indicate the standard error of the mean for 10 observers.
An example of the psychometric functions estimated for one participant for each testing day and each response modality and goodness of fit values are available in the Supplementary Materials.

In line with the results of Experiment 1, there was no indication that performance is better in the case of button presses or saccadic responses as compared to verbal responses. We found an interaction between response modality and testing day showing that the ISI for which a threshold of 75% correct is reached may be longer for saccadic than manual response, but only on the first testing day. This might indicate that sensitivity in the currently employed shape localization task indeed varies between response modalities under specific conditions. However, worse performance in the case of saccadic responses as compared to manual and verbal responses is opposite to what was shown in previous studies (e.g., Hughes & Kelsey, 1984). Thus, more errors for saccadic responses are unlikely due to changes in stimulus processing but rather by response execution errors, which are more likely for fast responses. Participants mentioned that the block with saccadic responses was very tiring, thus, it may have been more difficult to perform this specific task than the others, which explains the differences in lapse rate. We observed that performance improved over time for all response modalities. The estimated threshold was longer on the first testing day than on the second and the third day, thus, our results again do not support the idea that perceptual learning concerns the selective development of specific S-R links.

5. General discussion

It is often assumed that accuracy in binary decision tasks is independent of response modality. However, this seems less obvious for tasks concerning skilled behavior where sensori-motor contingencies are key such as riding a bike. Hence, the question arises to what degree response modality influences response accuracy.

We used a simple square/diamond location discrimination task and mapped stimuli on manual, verbal, and saccadic responses. The rationale was that if there are specific sensori-motor contingencies, then, there may be differences in accuracy in the case of near-threshold stimulation. Specifically, fast, saccadic responses may benefit stronger from S-R links than the other two response modalities used here. However, this was not the case. For longer ISIs, the target was clearly visible whereas for short ISIs the mask strongly impeded the visibility of the target. Assuming that verbal responses rely more on conscious processing than manual and saccadic responses, we expected differences in performance between the different response modalities. However, we found no deterioration of performance for verbal as compared to manual and saccadic responses, for all ISIs.

Other studies have found differences between response modalities supporting the presence of specific sensori-motor contingencies. For example, Bekkering and Neggers (2002) showed that observers were better in detecting the size and orientation of an object when they were asked to prepare to grasp this object than when they were asked to reach for it. However, these effects may be explained in other ways, as the focus of attention may simply be different depending on the type of the prepared action. Hughes and Kelsey (1984) asked participants to detect a near-threshold flash. Performance was better when observers performed a saccade towards the target than when they had to make a button press. However, the difference may be also explained by the presence of exogenous saccades that originate from the tecto-pulvinar pathway. Jaśkowski and Sobieralska (2004) showed that the difference between saccadic and manual response modalities disappeared when endogenous saccades were made, which is in line with our findings.

It has also been proposed that information for more automatic and unconscious reactions (e.g., manual responses) is fast accessible, but also short-lasting (Breitmeyer, 2014; Livingstone & Hubel, 1988; Milner & Goodale, 1995; Schen & McIntosh, 2010). Thus, fast saccadic reactions may benefit more from specific S-R links. Larger priming effects when observers respond under time pressure (Forster & Davis, 1991; Greenwald, Draine, & Abrams, 1996) may be also explained by an initial boost in prime activity that strongly modulates responses under high time pressure, while in the case of low time pressure this priming effect is already diminished. In line with this idea, when a briefly presented disk is followed by a ring, detection of the disk is better in the case of a direct response than in the case of a delayed response (Lachter, Durgin, & Washington, 2000). In perceptual illusion, manual responses (e.g., grip aperture), in contrast to perceptual judgments, were unaffected by the illusions (Aglioti, DeSouza, & Goodale, 1995; Brenner & Smeets, 1996; Daprati & Gentilucci, 1997; but see Franz, Gegenfurtner, Bulthoff, & Fahle, 2000). However, this was observed only when responses were performed immediately after stimulus onset (Bridgeman, Peery, & Anand, 1997; Creem & Proffit, 1998; Hu & Goodale, 2000). These results support the view that facilitation of processing can be observed for fast motor responses, but not for slower responses. However, we observed the same pattern of data when observers responded without (Experiment 1) and with time pressure (Experiment 2). Reaction time for saccadic responses was shorter than for manual and verbal responses, however, it did not lead to better performance. Hence, the lack of a difference in sensitivity for different response modalities cannot be explained by a decay of information before the response is executed.

S-R links may change over time due to perceptual learning (Hernandez & Lefton, 1977; Hogben & Di Lollo, 1984; Schwiedrzik et al., 2009). These effects seem mainly present in the case of localization tasks, while no improvement in target discrimination was observed when observers were asked to withhold their verbal responses for 600 ms (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). These results indicate that perceptual learning might be limited to direct stimulus-response (S-R) links specific for certain response modalities. However, in our experiments perceptual learning was observed for all response modalities. Thus, our results do not support the view that specific S-R links may improve over time only for certain fast responses. Nevertheless, S-R links could still have been developed but they are comparable for all modalities used in our study.
Our null results are unlikely to be affected by the low number of participants because, first, the presence of any effect of response modality is not visible in the data. Second, a Bayesian analysis (see Masson, 2011) confirmed that the “null” hypothesis is a much more likely explanation than the H1 hypothesis. Third, even though there is no effect of response modality, we found learning in both experiments. Thus, the number of participants we used is sufficient to produce significant effects in principle.

In conclusion, our findings suggest that response accuracy in visual binary decision tasks does not depend on response modality. Null results are not easy to interpret. One possibility is that indeed in our experiments stimulus processing is independent of the response modality. Another possibility is that there are differences in accuracy but our paradigm was not sensitive enough to reveal them. Another possibility is that there are differences in general but accuracy is identical in independent of the response modality. Null results are not easy to interpret. One possibility is that indeed in our experiments stimulus processing is independent of the response modality. Another possibility is that there are differences in accuracy but our paradigm was not sensitive enough to reveal them. Another possibility is that there are differences in general but accuracy is identical for the specific settings in our experiment. As mentioned, we do not deny that motor-contingencies exist. They do definitely for reflexes, in all sorts of sports, and wherever fast reactions are required. However, our results suggest that there are no differences in accuracy when there are no specific (trained) stimulus-response mappings.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2016.05.005.

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