Mechanisms of selection in auditory localization tasks: Evidence from the spatial negative priming effect

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Zusammenfassung

Reaktionen auf einen Reiz, an dessen Ort zuvor ein Distraktor dargeboten wurde, sind typischerweise verlangsamt und manchmal fehleranfälliger als Reaktionen auf einen zuvor unbesetzten Ort. Dieser Befund wird als *räumlicher Negativer Priming-Effekt* bezeichnet. Der Effekt wird weitgehend zur Untersuchung von Selektionsmechanismen verwendet. Eine typische Aufgabe zum räumlichen Negativen Priming beinhaltet zwei aufeinanderfolgende Darbietungen, einen *Prime* gefolgt von einem *Probe.* Die Aufgabe der Teilnehmer besteht darin, für jede Darbietung den Ort eines definierten Zielreizes in Anwesenheit eines gleichzeitig präsentierten Distraktors zu bestimmen. In sogenannten *Ignoriertes wiederholt*-Durchgängen wird der Zielreiz im Probe am Ort des Distraktors aus dem vorherigen Prime dargeboten. In der visuellen Modalität wird der räumliche Negative Priming-Effekt mit der Inhibition von Distraktororten oder ihren aufgabenabhängig zugeordneten Reaktionen erklärt, während keine Evidenz für diese Mechanismen in akustischen Varianten der Aufgabe gefunden wurde. Hingegen scheint die Leistung in akustischen Aufgaben zum Negativen Priming hauptsächlich durch das Auftreten von Identitäts-Ortsdiskrepanzen bestimmt zu sein. Konkret sind Reaktionen auf den Ort des Zielreizes im Probe beeinträchtigt, wenn eine Reizänderung an diesem Ort auftritt oder sich der Darbietungsort des spezifischen Reizes zwischen aufeinanderfolgenden Präsentationen ändert. Dieser Befund impliziert, dass Merkmale von wahrgenommenen Reizen in gemeinsame Repräsentationen, sogenannte *Objektdateien,* integriert werden. Die fünf Experimente der vorliegenden Dissertation untersuchten, ob Inhibition ein Bestandteil der räumlichen Distraktorverarbeitung in der akustischen Modalität ist. Dazu wurden räumliche Aufgaben zum Negativen Priming in Experiment 1, 2, 3 und 4B verwendet. Experiment 1 isolierte die Effekte von Reaktions- und Ortswiederholung zwischen Primedistraktor und Probezielreiz auf die Reaktionsleistung. Experiment 2 untersuchte, ob Evidenz für inhibitorische Distraktorverarbeitung vom Intervall zwischen Primereaktion und dem zugehörigen Probe abhängig ist. Räumlich gerichtete Joystick- und Kopfbewegungen wurden in Experiment 3 und 4B verwendet, um das Auftreten einer Aktivierungs-Inhibitionsabfolge für Reaktionen zu maximieren, die Distraktoren zugeordnet waren. Experiment 4A testete, ob Kopfbewegungsreaktionen durch räumlich dargebotene Distraktorklänge aktiviert werden, was eine notwendige Bedingung für das Auftreten eines Inhibitionsprozesses darstellt. Alle Ex-

perimente zum akustischen räumlichen Negativen Priming zeigten ein Ergebnismuster, das vollständig mit den Vorhersagen der Merkmalsdiskrepanzhypothese übereinstimmt und somit nachdrücklich auf die Bedeutung von Objektbindung in der akustischen Modalität hinweist. Dennoch deuten die Ergebnisse aus Experiment 4A darauf hin, dass reaktionsbezogene Inhibition auch in der akustischen Verarbeitung wirkt, wenn hochkompatible Reaktionen verwendet werden. Darüber hinaus scheint Reaktionsinhibition in der akustischen Verarbeitung kurzlebig zu sein und somit nur die unmittelbare Reaktion zu beeinflussen. Zusammen zeigen die gegenwärtigen Ergebnisse, dass akustische Selektion auf einem dualen Mechanismus beruht, der sich vornehmlich auf Objektbindung stützt, aber auch die Inhibition von Distraktorreaktionen umfasst.

Abstract

Responding to a stimulus at a location that contained a distractor in the prior presentation is usually slowed-down and sometimes more error-prone as compared with responding to a previously unoccupied location. This finding has been termed the *spatial negative priming effect*. It is widely used to investigate the mechanisms underlying selection. A typical spatial negative priming task comprises two successive presentations, a *prime* followed by a *probe*. Participants have to indicate the location of a designated target in the presence of a simultaneous distractor in each presentation. In so-called ignored repetition trials, the probe target is presented at the location of the former prime distractor. In vision, the spatial negative priming effect is usually attributed to the inhibition of distractor locations or their task-assigned responses, while no evidence for these mechanisms has been found in auditory versions of the task. In contrast, performance in auditory spatial negative priming tasks seems to be mainly determined by the occurrence of identity-location mismatches. Specifically, responding to the location of the probe target sound is impaired when a stimulus change occurs at the location or the respective sound changes its location between successive presentations. This finding implies that features of perceived stimuli are integrated into common representations, so-called *object files*. The five experiments of the present thesis investigated whether inhibition is part of spatial distractor processing in audition. To this end, spatial negative priming tasks were employed in Experiment 1, 2, 3, and 4B. Experiment 1 isolated the effects of response and location repetition between prime distractor and probe target on performance. Experiment 2 investigated whether evidence for inhibitory distractor processing depends on the interval between the prime response and the corresponding probe. Spatially directed joystick and head movement responses were employed to maximize the occurrence of an activation-inhibition sequence for distractor-assigned responses in Experiment 3 and Experiment 4B, respectively. In Experiment 4A it was tested whether head movement responses to spatially presented distractor sounds are activated which constitutes a necessary precondition for inhibition to apply. All auditory spatial negative priming experiments revealed a pattern of results that fully conformed to the predictions of the feature mismatching hypothesis, strongly indicating the importance of object file binding in the auditory modality. However, the results of Experiment 4A indicate that response-related inhibition also operates in auditory pro-

cessing when highly compatible responses are employed. Moreover, response inhibition seems to be short-lived in auditory processing, thereby only affecting immediate responding. Together, the current results indicate that auditory selection is achieved by a dual mechanism which predominantly relies on object file binding for target and non-target events but also entails the inhibition of distractor responses.

Introduction

Given that most environments contain a vast number of stimuli that could potentially lead to action, the seemingly effortless conversion of intentions into behavior denotes a remarkable feature of the human information processing system. Goal-directed behavior in multistimulus environments requires the successful processing of information that conforms to the requirements of the task at hand as well as preventing currently irrelevant information from gaining access to behavior. This central aspect of human information processing is termed *selection* and a large body of research has been devoted to identifying its underlying mechanisms.

Based on the pioneering experimental work of Cherry (1953), several models of selection were proposed. These models share the assumption that relevant and irrelevant aspects are processed differently during information transmission from perception to action, but vary with respect to the stage at which selection takes place. According to the *filter model of attention* (Broadbent, 1970), selection occurs during a precategorical stage of stimulus processing (*early selection*). It assumes that physical features of all perceived sensory events (e.g., color, shape, loudness, or spatial location) are encoded in parallel and are stored in a short-term buffer. Unless further processed, memory traces within the buffer are only available for a short period of time. Following this model, selection occurs by applying a filtering process to the content of the buffer that extracts features that conform to predefined criteria. Selected information is transferred to subsequent processing stages, thereby preventing their decay, while all non-selected content of the buffer rapidly deteriorates and is ultimately lost.

In contrast to an early selection mechanism, the model proposed by Deutsch and Deutsch (1963), assumes that all perceptual input is processed up to a postcategorical level at which information is analyzed for meaning. Only then a selection mechanism determines which information is most relevant to the current goals and intentions and translates them into appropriate responses (*late selection*). In sum, both models differ with respect to the specific locus (early vs. late) and the criteria (physical features vs. meaning) of selection, but agree upon the notion that the extraction and maintenance of currently relevant information and the passive decay of non-selected information denote the prominent mechanisms (see also Van der Heijden, 1981).

However, several findings extended this view by providing compelling evidence for a selection mechanism that actively operates on task-irrelevant information.

First experimental evidence for a selection mechanism that is directly applied to task-irrelevant information stems from a study concerned with sequence effects in the well-known Stroop task (Dalrymple-Alford & Budayr, 1966, Experiment 2; see Stroop, 1935, for the original description of the task). In some trials, participants were successively exposed to color words that were, in turn, displayed in colored letters. The task required to name the color of the letters and to ignore the meaning of the color word. In incompatible trials, the color of the letters differed from the semantic content of the word. The results showed a typical *Stroop effect* indicated by prolonged and less accurate naming responses in incompatible trials as compared with control trials which comprised a string of colored "X" letters. Most important for the present purpose, performance was additionally slowed-down (as compared with the respective control trials) when the to-be-named letter color in the current trial matched the to-be-ignored word meaning of the previous trial. This finding was interpreted as evidence for a mechanism that directly operates on task irrelevant aspects, rendering them less available for a short period of time and impairing subsequent responding.

In his seminal article, Tipper (1985) adopted the rationale of identifying the mechanisms of selection by studying their consequences on future processing. To this end, Tipper employed a priming paradigm in which each trial consisted of two successive presentations, a *prime* followed by a *probe.* Each presentation comprised a task-relevant stimulus (*target*) and a simultaneously presented stimulus that had to be ignored (*distractor*). In prime and probe, participants saw two superimposed line drawings, each displayed in a different color. The task was to name the red target object while the green distractor object had to be ignored. Most important to the present purpose, the relation between stimuli in the prime and probe was systematically varied to generate two crucial trial types: In so-called *ignored repetition* trials, the probe target was identical to the previously ignored prime distractor, while *control* trials were devoid of any repetitions between successive presentations. The results showed that naming latencies for probe targets were longer in ignored repetition trials as compared with control trials. This finding was taken as further evidence that selection does not only entail the privileged processing of task-relevant information but also includes mechanisms that operate on non-target information. Otherwise, probe responding in ignored repetition trials would not have been affected as compared with probe targets that were not presented in the previous prime. In opposition to the facilitative effect of successively processing the same object (e.g., Jacoby, 1983; Logan, 1990; Malley & Strayer, 1995; Scarborough, Cortese, & Scarborough, 1977), slowed-down and sometimes more error-prone responding to previously irrelevant stimuli was termed the *negative priming effect* (see also Marcel, 1983). Since its first description in visual tasks, the negative priming effect has been widely used to study the mechanisms that prevent irrelevant information from influencing goal-directed behavior in auditory (e.g., Banks, Roberts, & Ciranni, 1995; Buchner & Steffens, 2001; Mayr & Buchner, 2006), and tactile processing (Frings, Amendt, & Spence, 2011; Frings, Bader, & Spence, 2008) as well as in clinical (e.g., Laplante, Everett, & Thomas, 1992; Leung, Lee, Yip, Li, & Wong, 2009; Vitkovitch, Bishop, Dancey, & Richards, 2002) and in developmental studies (e.g., Amso & Johnson, 2005; Buchner & Mayr, 2004; Müller, Dick, Gela, Overton, & Zelazo, 2006).

The negative priming effect is usually explained by the operation of a distractor inhibition mechanism or a memory-based retrieval of inappropriate prime information (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995; Mayr & Buchner, 2007; Tipper, 2001). Extending the tentative conclusion proposed by Dalrymple-Alford and Budayr (1966), the inhibition account (e.g., Houghton & Tipper, 1994; Tipper, 1985, 2001; Tipper & Cranston, 1985) posits that the representations of distractor stimuli are actively inhibited to facilitate processing of relevant information. As a consequence, representations of distractor stimuli are assumed to be less accessible for a period of time. Following this account, presenting the former prime distractor as the probe target results in delayed responding due to residual inhibition of that stimulus. Alternatively, the episodic retrieval model (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) assumes that repeating a stimulus between prime distractor and probe target acts as a retrieval cue to the prime episode. Most important, the retrieved episode contains the information that no response was executed to the specific stimulus during the prime. The retrieved “do-not-respond” information tied to the stimulus during prime processing conflicts with the need to respond to the same stimulus at the time of the probe. It is assumed that the negative priming effect reflects the time-consuming need to resolve this conflict before an appropriate response can be generated. Although retaining the idea that the negative priming effect is caused by the retrieval of inadequate prime information at the time of the probe, the prime-response variant of the episodic retrieval theory (Mayr & Buchner, 2006; see also Rothermund, Wentura, & De Houwer, 2005) differs with respect to the nature of the response conflict. Specifically, it is proposed that distractor-to-target repetitions between prime and probe retrieve the response previously executed to the prime target (see, e.g., Frings, Rothermund, & Wentura, 2007 for evidence that prime responses are also retrieved by distractor-to-distractor repetitions between successive presentations). The retrieved prime target response conflicts with responding to the probe because, in ignored repetition trials, the correct response to the probe target usually differs from the response to the former prime target. Following the prime-response retrieval account, this conflict has to be overcome before a correct response can be given, resulting in the negative priming effect. With respect to the explanatory power of the described accounts, it is widely assumed that the negative priming effect is caused by the joint operation of distractor inhibition and memory-based mechanisms (e.g., Tipper, 2001), but a growing empirical basis favors a memory retrieval mechanism as its main determinant (Mayr & Buchner, 2007).

Two variants of the negative priming paradigm are distinguished based on the specific response-relevant features in the task. In the previously described *identity negative priming* tasks, target and distractor objects usually differ with respect to their color or their particular location in space, but responses are typically assigned to the specific identity of the stimuli (e.g., Tipper, 1985; Tipper & Cranston, 1985). In contrast, the target in a so-called *spatial negative priming* task has to be discerned from a concurrently presented distractor on the basis of a non-spatial feature such as color or form, but the specific location of the target object has to be reported.

A spatial negative priming task was first employed by Tipper, Brehaut, and Driver (1990) in the visual modality. For example, in their Experiment 1, prime and probe displays comprised a target symbol (“@”) and a simultaneously presented distractor symbol (“+”) presented at two out of four predefined screen locations. Each location was assigned to a spatially compatible response key. Participants had to indicate the location of the target symbol, while the response assigned to the location of the distractor symbol had to be withheld. In ignored repetition trials, the probe target was presented at the location that contained the distractor symbol in the previous prime while no location repetitions occurred in control trials. Responding to the location of the probe target in ignored repetition trials was delayed as compared with control trials. This finding denotes the so-called *spatial negative priming effect* which has been replicated since in the visual modality (e.g., Buckolz, Goldfarb, & Khan, 2004; Chao, 2009; Milliken, Tipper, Houghton, & Lupiáñez, 2000; Milliken, Tipper, & Weaver, 1994; Neill & Valdes, 1992; Tipper, Weaver, & Milliken, 1995).

Tipper et al. (1990) argued that the spatial variant of the task is particularly suitable to study human information processing because its requirements resemble the processing demands posed by everyday situations. In most environments, currently relevant objects are defined by their respective identities while responding to these objects typically refers to their specific location in space (like reaching for a coffee cup amongst other objects on a table). The experiments presented here test predictions derived from models designed to explain how the cognitive system deals with objects presented at to-be-ignored locations while attention is focused on task-relevant information at other positions in space. Therefore, the focus here is on the spatial negative priming paradigm.

The explanations of the spatial negative priming effect resemble the accounts proposed for identity-based negative priming: The traditional *distractor inhibition account* (Milliken et al., 2000; Tipper et al., 1990) proposes that the internal representation of a distractor location is actively inhibited to facilitate target processing and to prevent false responding. As a consequence, the internal representation of the prime distractor location is rendered less accessible for a short period of time and its inhibitory status persists into the corresponding probe presentation. Therefore, the probe target is presented at a still-inhibited location in ignored repetition trials, hampering target processing at that location. In contrast, this is not the case in control trials in which no location repetition occurs between successive presentations. The spatial negative priming effect is thus an after-effect of inhibitory distractor processing. In essence, impaired performance in ignored repetition trials is attributed to the operation of an inhibitory mechanism applied to spatial representations of distractor events. Moreover, the episodic retrieval account posits that conflicting prime response information (i.e., do-not-respond information or the executed response to the prime target) is retrieved when a prime and probe stimuli share a location (Frings & Möller, 2010; Neill & Valdes, 1992; Neill et al., 1992).

An alternative account of the spatial negative priming effect in vision was originally proposed by Park and Kanwisher (1994). The so-called *feature mismatching hypothesis* assumes that slowed-down responding to stimuli at previously ignored locations is not an after-effect of inhibition applied to distractor locations or a memory-retrieval of prime response information, but derives from a feature change at the repeated location between successive presentations. According to the feature mismatching hypothesis, identities and spatial locations of perceived stimuli are integrated into common representations, so-called *object files*, irrespective of their status as target or distractor in the current presentation (Kahneman, Treisman, & Gibbs, 1992; Treisman, 1993; Treisman & Gelade, 1980). It is further proposed that object files are stored in memory and that the whole content of an object file is retrieved whenever a single feature of the object file is encountered in a subsequent presentation. The content of the retrieved object file is then compared with the currently processed object and any deviations lead to a time-consuming updating of the respective object file. Therefore, object changes between successive presentations are associated with a cost in latency and probably in accuracy of responding while repeating identical objects between subsequent presentations should not affect performance or even yield reduced response times and errors.

Park and Kanwisher (1994) argued that the visuospatial negative priming effect obtained in the study of Tipper et al. (1990) can be explained by a feature mismatch at the location shared by the prime distractor and the corresponding probe target in ignored repetition trials. Because target and distractor identities remained constant across trials, presenting the probe target stimulus (“@”) at the location of the former prime distractor (“+”) in ignored repetition trials led to a concomitant mismatch between symbol identities at the repeated location whereas no such mismatch occurred in control trials devoid of any location repetitions. Park and Kanwisher (1994, Experiment 4) manipulated the occurrence of a feature mismatch in ignored repetition trials to determine its contribution to the visuospatial negative priming effect. To this end, they replicated the task employed by Tipper et al. (1990) but switched target and distractor symbols between prime and probe. In the prime, participants had to indicate the location of a target symbol (“X”) while ignoring a distractor symbol (“O”). Most important, target and distractor symbols reversed for the subsequent presentation so that the probe demanded a response to the location of the “O” symbol while responding to the location of the “X” symbol had to be withheld. With this change in instructions, ignored repetition trials no longer entailed an identity mismatch at the repeated location (resulting in so-called *symbol-match* trials). Most important, the results did not show impaired performance but rather facilitated responding in symbol-match trials as compared with control trials. This finding contradicts the predictions of the distractor inhibition account (Tipper et al., 1990), because processing of *all* stimuli—regardless of whether they comprise a location-identity mismatch or not—should be impaired at a previously inhibited location. Instead, the results conform to the prediction of the feature mismatching hypothesis of spatial negative priming and demonstrate that object file binding occurs for distractor events and that the retrieval of object files can impair performance if their content does not fully match the currently processed object.

Although the contribution of feature mismatching on visuospatial negative priming was initially demonstrated by Park and Kanwisher (1994), the majority of later studies excluded feature mismatching as the *sole* determinant of the visuospatial negative priming effect. For example, Milliken et al. (1994, Experiment 3) employed a visuospatial negative priming task in which prime and probe presentations comprised two (out of four) letters of different colors presented at two (out of four) display locations. In each presentation, a color patch in the center of the screen determined the color of the to-be-attended letter. Location, color and identity features as well as their respective combinations were repeated between prime distractor and probe target in ignored repetition trials while trials devoid of any repetitions served as control. Most important to the present purpose, the results showed a reliable spatial negative priming effect when the probe target was identical to the preceding prime distractor with respect to location, color, and identity. The occurrence of reliable spatial negative priming effects in the absence of a feature mismatch has led to the conclusion that the effect is at least determined by more than one process, empirically favoring inhibition-based accounts as its main cause (see Milliken et al., 2000; Tipper et al., 1995, for additional findings supporting this conclusion and a discussion of the potential functional interplay between feature mismatching and inhibitory accounts).

In line with the widespread notion that the visuospatial negative priming effect is predominantly caused by an inhibitory mechanism, the *response inhibition account* (e.g., Buckolz et al., 2004), however, suggests a motor-related origin of the effect. Specifically, distractor-assigned responses instead of their spatial representations are assumed to be inhibited as part of distractor processing. The response inhibition account proposes that responses assigned to target and distractor locations are automatically activated and strive for the control of action in visuospatial negative priming. To prevent false responding, the response activation triggered by the location of the distractor stimulus is counteracted by an inhibitory mechanism that suppresses the non-target response to a sub-baseline level. As a consequence, the accessibility of that specific response is reduced for a period of time, delaying its subsequent execution. In traditional spatial negative priming tasks, each location is assigned to a distinct response key, implying that a prime distractor-to-probe target location repetition in ignored repetition trials comes along with the requirement to execute the former prime distractor response (e.g., Tipper et al., 1990). Therefore, the visuospatial negative priming effect in previous experiments could be attributed to either the time-consuming need to overcome the inhibitory status of the currently required response or the specific location.

To determine the locus of the effect, Guy and Buckolz (2007) disentangled the contribution of location and response repetition on performance by employing a modified location-to-response mapping in a visuospatial negative priming paradigm. In this study, participants had to localize a target stimulus presented at one of four horizontally aligned display locations while responses to a distractor at another location had to be withheld. The two locations to the left of fixation were assigned to a common response key. The same was true for the two locations to the right of fixation. This arrangement allowed to assess the sole effect of executing a previously withheld response by presenting the probe target stimulus at a previously unoccupied location that was yet assigned to the same response key as the former prime distractor. Performance in these so-called *response control trials* was compared with traditional ignored repetition trials (comprising location as well as response repetition between prime distractor and probe target), and control trials (without any repetitions between successive presentations). Interestingly, response times in response control trials were reliably longer as compared with control trials, thereby strongly supporting the response-based inhibition explanation of the visuospatial negative priming effect. Furthermore, responding in traditional ignored repetition trials did not differ from response control trials suggesting that additionally presenting the probe target at the location of the former prime distractor does not delay responding beyond the slowing effect of executing a previously withheld response (for replications, see Buckolz, Edgar, Kajaste, Lok, & Khan, 2012; Buckolz, Fitzgeorge, & Knowles, 2012; Fitzgeorge, Buckolz, & Khan, 2011). While the former result provided compelling evidence for the operation of response-related inhibition, the latter finding was at odds with a location-based inhibition account of visuospatial negative priming (Milliken et al., 2000; Tipper et al., 1990). Therefore, the authors concluded that distractor-assigned responses rather than their spatial representations are inhibited as part of visual distractor processing, leading to impaired performance when the specific output is required in a subsequent presentation. Still, there is an ongoing debate about whether spatial- or response-related features (or both) of task-irrelevant events are inhibited as part of visual distractor processing (see Neill, Valdes, & Terry, 1995, for independent evidence for location-based inhibition in visuospatial negative priming). However, it is widely agreed upon that the visuospatial negative priming effect indicates inhibitory distractor processing (for a review, see Tipper, 2001), with a growing empirical basis supporting the response inhibition explanation (e.g., Buckolz, Edgar, et al., 2012; Buckolz et al., 2004; Fitzgeorge et al., 2011; Guy, Buckolz, & Khan, 2006).

Despite its widespread use to investigate the mechanisms governing selection in vision, the spatial negative priming paradigm has only recently been employed to identify corresponding processes in the auditory domain (Mayr, Buchner, Möller, & Hauke, 2011; Mayr, Hauke, & Buchner, 2009; Mayr, Möller, & Buchner, 2014). This is somewhat surprising because the auditory system is frequently confronted with spatially distributed streams of concurrent sound information that compete for processing and, ultimately, for the control of action (for reviews, see Arnott & Alain, 2011; Bregman, 1990; Carlyon, 2004; Kubovy & Van Valkenburg, 2001). Moreover, Banks et al. (1995) argued that whereas peripheral mechanisms such as eye movements contribute to visual selection, comparable mechanisms are not present in audition so that selection in the auditory modality is thought to be governed by central processing. As the spatial negative priming paradigm has been proven fruitful in determining the cognitive mechanisms of selection in vision, the task can be deemed eligible for investigating their auditory counterparts.

The first study concerned with the spatial negative priming effect in audition has been reported by Mayr et al. (2009). In this study, two simultaneous sounds (piano, crow) were emitted from two out of four speakers. Two speakers were placed to the left and right in front of the participants while two more speakers were placed behind them. Each sound presentation was preceded by a picture cue indicating the to-be-attended stimulus. The task required determining the speaker that emitted the target sound by pressing a spatially compatible button on a keyboard. In ignored repetition trials, the probe target sound was presented from the speaker that emitted the distractor sound during the prime trials while no location repetition occurred in corresponding control trials. Note that, due to the specific assignment of speaker locations and response keys, location repetitions always implied the need to execute a previously withheld response in addition to reacting to a previously ignored location in ignored repetition trials. Mayr et al. varied whether prime distractor and probe target comprised the same sound or different sounds to determine the impact of a feature mismatch (Park & Kanwisher, 1994) on performance in the auditory version of the task. The results showed that responding to the probe target was not generally impaired when it was presented from a speaker that emitted the to-be-ignored sound in the preceding prime and also required the execution of a previously withheld response. This finding was interpreted as evidence against the operation of an inhibitory mechanism that suppresses either spatial representations of distractor events or their task-assigned responses. Instead, performance in ignored repetition trials strongly depended on the occurrence of a feature mismatch: As compared with control trials, responding to the location of the probe target was only delayed when prime distractor and probe target sounds mismatched, but did not differ when they comprised the same sound.

Beyond providing the first data from a spatial negative priming task in audition, the results of Mayr et al. (2009) also suggested that the mechanisms underlying spatial distractor processing differ between visual and auditory versions of the task: Whereas studies on the visuospatial negative priming effect largely support the notion that distractor-assigned responses are inhibited to prevent false responding (Buckolz et al., 2004), the results by Mayr et al. (2009) are not in line with this conclusion. Instead, their results fully conform to the predictions of the feature mismatching hypothesis (Park & Kanwisher, 1994).

The impact of feature mismatching on performance in auditory versions of spatial negative priming was further supplemented by a subsequent study (Mayr et al., 2011, Experiment 1). Material and procedure used in this study were comparable to that used in Mayr et al. (2009), but target and distractor sounds were drawn from a total of four animal voices (lamb, frog, bird, cat). By using a set of four speakers and four sounds, location and sound identity repetitions were manipulated orthogonally between prime distractor and probe target in the ignored repetition subdesign. Specifically, the probe target was presented from the speaker that emitted the prime distractor, but differed in sound identity in *sound-change, location-repeated* trials, while prime distractor and probe target comprised the same sound but differed in their position in space in *sound-repeated, location-changed* trials. *Sound-repeated, location-repeated* trials exhibited a full repetition of spatial and identity features between prime distractor and probe while *sound-changed, location-changed* trials were devoid of any sound identity or location repetitions and served as control trials. The results mirrored the findings by Mayr et al. (2009) in that responding to a previously ignored location was not generally impaired but was entirely determined by the occurrence of feature mismatches: Whereas probe responding in *sound-changed, location-repeated* trials was delayed, there was no slow-down in responding to *sound-repeated, location-repeated* trials. In addition, performance was impaired in *sound-repeated, location-changed* trials as compared with control trials. This finding is also at odds with a location-based or response-based inhibition account because neither the location nor the location-assigned response was repeated between prime distractor and probe target in these trials. In contrast, the authors argued that this finding denotes another case of a feature mismatch in which object file retrieval is triggered by the identity repetition between prime distractor and probe target but the spatial information stored in the object file is in conflict with the current probe target location.

To illustrate the results reported by Mayr et al. (2011, Experiment 1), the feature mismatching account proposes that presenting the prime target sound (e.g. “cat”) from the front left speaker and the sound of the prime distractor (e.g. “frog”) from the rear right speaker generates two object files each of which contains sound identity and spatial information about one event (resulting in object files containing “front left, cat” and “rear right, frog”, respectively). In ignored repetition trials, presenting a previously unused probe target sound (e.g. “lamb”) from the rear right speaker that emitted the distractor during the prime leads to the retrieval of the object file associated with that specific location information. In this case, the retrieved object file (“rear right, frog”) does not fully correspond to the currently processed target object in the probe (“rear right, lamb)” with respect to the sound identity information. Consequently, responding to the probe target object is delayed due to a time-consuming updating of, in this case, the identity information stored in the object file. In contrast, no updating process occurs when the retrieved object file fully conforms to the current stimulus and, therefore, performance is not affected. In the same vein, Mayr et al. (2011) argued that impaired performance in *sound-repeated, location-changed* trials can also be explained within the object file framework. Specifically, this finding suggests that object file retrieval can also be triggered by a sound repetition between prime and probe. With respect to the present example, this is the case when the sound encoded in an object file (e.g. "rear right, frog") is re-used as the target sound in the corresponding probe, but is emitted from a different speaker (e.g. "rear left"). In this case, the object file established for the prime distractor (i.e. "rear right, frog") is retrieved by the repetition of the sound but differs from the current probe target object with respect to the location information ("rear right" vs. "rear left" for prime distractor and probe target, respectively). Again, object file information is assumed to be updated before a probe response is generated, leading to delayed responding in *sound-repeated, location-changed* trials.

In sum, multiple studies on visuospatial negative priming suggest that goal-directed behavior is achieved by the suppression of distractor-assigned responses (e.g., Buckolz et al., 2004; Fitzgeorge et al., 2011; Guy et al., 2006). In contrast, all previous results of auditory spatial negative priming tasks did not find any evidence for inhibitory distractor processing, but solely conformed to the predictions of the feature mismatching hypothesis (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014). Assuming that the mechanisms underlying the spatial negative priming effect are indicative of how the cognitive system prevents irrelevant information from gaining access to behavior during information processing, it might be concluded that considerably different mechanisms guide goal-directed behavior in vision and audition. However, this inference derives from the outcomes of studies employing comparable methods and, moreover, is mainly based on the absence of inhibitory after-effects found in auditory spatial negative priming (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014). Therefore, this conclusion requires a broader empirical basis and alternative explanations for this outcome have to be considered before it can be ultimately drawn.

The aim of the present series of experiments is twofold. First, five experiments were conducted to provide a broader empirical basis to further specify the mechanisms underlying distractor processing in audition. Second, possible alternative explanations for the absence of inhibitory after-effects in auditory variants of the spatial negative priming task were addressed in four experiments (Exp. 1-3 and Exp. 4B).

Specifically, Experiment 1 employed the rationale of mapping several locations to a common response key (e.g., Guy & Buckolz, 2007) to disentangle the contributions of location and response repetition to performance in auditory spatial negative priming. To anticipate, the results of Experiment 1 did not reveal any evidence for inhibitory distractor processing. Therefore, Experiment 2 tested whether the absence of inhibitory after-effects may have been due to an inappropriate timing of prime and probe events in previous studies of auditory spatial negative priming. Finally, spatially directed joystick (Experiment 3) and head movement (Experiment 4B) responses were used in an auditory spatial negative priming task to determine whether inhibitory after-effects emerge when distractor-related response activation is provided. In this vein, Experiment 4A investigated whether head movement responses to spatially presented distractor sounds are processed up to a level of motor activation. The complete description of the methods and the results of each experiment is provided in the appended manuscript and publications. In the following, a brief overview of each experiment is given.

Experiment 1[1]

Experiment 1 was designed to isolate the impact of executing a response that had been assigned to the previous prime distractor from the influence of responding to a sound at a previously ignored location. Due to the distinct mapping of speaker locations to responses, results from prior studies have been inconclusive with respect to the contribution of response-related inhibition in auditory spatial negative priming. Experiment 1 was conducted to remedy this situation and to gain further insight into the nature of distractor processing in the auditory modality. To this end, Experiment 1 employed a modified location-to-response mapping in an auditory spatial negative priming task which has been successfully applied to assess response-related inhibition in vision (e.g., Buckolz et al., 2004; Fitzgeorge et al., 2011; Guy et al., 2006). The mapping was comparable to the procedure used by Guy and Buckolz (2007) in the

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[1] For details, see Möller, M., Mayr, S., & Buchner, A. (2013). Target localization among concurrent sound sources: No evidence for the inhibition of previous distractor responses. *Attention, Perception, & Psychophysics, 75*(1), 132-144. doi: 10.3758/s13414-012-0380-2.

visual modality. Specifically, eight sound locations were pairwise assigned to only four response keys. As in the study by Guy and Buckolz (2007), this location-to-response mapping allowed the generation of (1) trials with location and response repetitions between prime distractor and probe target (traditional *ignored repetition* trials), (2) trials that solely required the execution of the former distractor-assigned response (*response control* trials), and (3) trials devoid of any response or location repetitions (*control* trials).

Because prior studies of auditory spatial negative priming strongly supported the feature mismatching hypothesis (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014), the predictions derived from this hypothesis were directly pitted against the inhibition accounts. This was done by orthogonally varying the occurrence of a sound repetition (repeated vs. changed) between successive presentations. All three trial types (ignored repetition, response control, and control trials) were once instantiated with (sound repeated) and without (sound changed) a sound repetition between the non-target event in the prime and the target sound in the corresponding probe. This procedure yielded ignored repetition trials with and without a feature mismatch at the repeated location. To reiterate, the feature mismatching hypothesis (Park & Kanwisher, 1994) predicts slowed-down responding in ignored repetition trials (as compared with control trials) only in case of a sound change. In contrast, response times in ignored repetition trials containing an exact sound repetition should not differ from their respective control trials. Moreover, performance in response control trials should be comparable to performance in control trials[2].

Hypothesis testing was based on two crucial trial type comparisons within each level (repeated vs. changed) of the sound repetition factor: Comparing performance between control and response control trials was informative with respect to the operation of response-related inhibition. If automatic response activation followed by response inhibition takes place for auditory distractors, responding in response control trials should be impaired as compared with control trials. Moreover, the comparison

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[2] Mayr et al. (2011) argued that object file retrieval can by triggered by a sound repetition between successive presentations. Note that, in half of the trials, prime distractor and probe target comprise the same sound. By definition, prime distractor and probe target differ with respect to their location in space in control and response control trials. Consequently, a feature mismatch might also occur in these trials that could additionally affect performance. However, as a feature mismatch occurs in both respective response control trials and control trials performance differences between these trials are informative with respect to the operation of response inhibition in auditory distractor processing.

between performance in response control and traditional ignored repetition trials provided insight about the contribution of a location-based inhibition mechanism in auditory spatial negative priming. If location inhibition takes place, ignored repetition trials should be slowed down as compared with response control trials. The standard negative priming effect (i.e., the comparison between ignored repetition and control trials) was also determined and tested but note that this effect is equivocal with respect to the underlying mechanism(s) because it confounds response and location repetition effects. The results are shown in Figure 1.

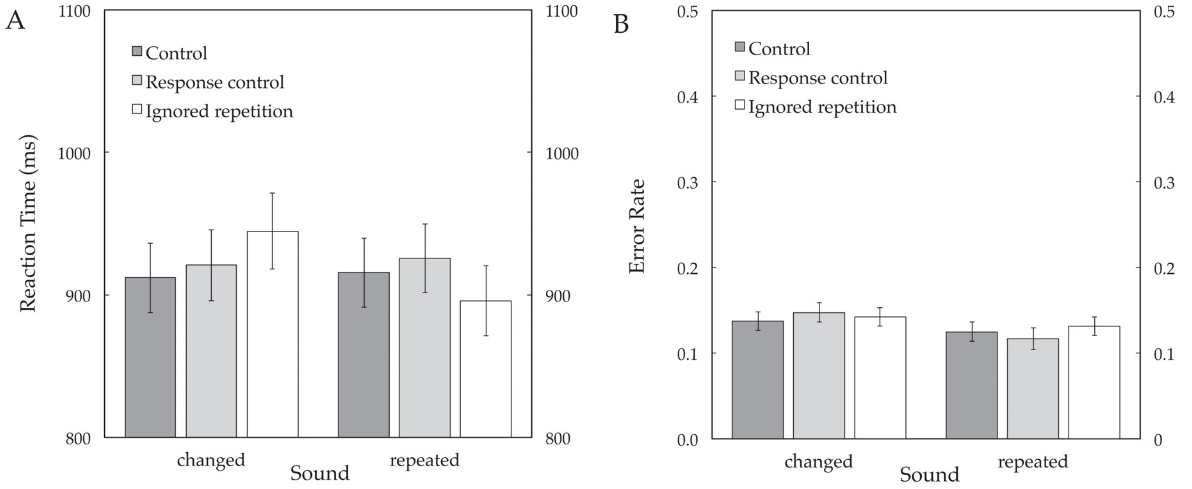

Figure 1: Mean reaction times (A) and error rates (B) as a function of trial type (control, response control, ignored repetition) and sound repetition (repeated vs. changed) in the ignored repetition subdesign of Experiment 1. The error bars depict the standard errors of the means.

Experiment 1 was designed to disentangle the influence of response inhibition and feature mismatching effects on auditory distractor processing. For trials with a sound change between prime distractor and probe target, responding in ignored repetition trials was prolonged as compared with control trials, denoting the traditional spatial negative priming effect. Although different mechanism are assumed, this finding is predicted by inhibition accounts (e.g., Buckolz et al., 2004; Tipper et al., 1990) as well as the feature mismatching hypothesis (Park & Kanwisher, 1994). Comparing response control to control trials revealed that the need to execute a prior distractor response did not affect responding. This result contradicts the predictions of the response-inhibition account that has been put forward to explain visual spatial negative priming (e.g., Buckolz et al., 2004). Further, responding to the probe target at the previous distractor location was impaired, as indicated by slowed-down responses in ignored repetition compared to response control trials. Together, the results suggest that impaired performance in the present ignored repetition trials is not determined by response inhibition, but might be caused by location-based inhibition or the occurrence of a feature mismatch at the repeated location. Comparisons among sound repeated trials allowed to test these accounts against each other.

For sound repeated trials, response times were equivalent for response control and control trials mirroring the results from sound changed trials. This finding further suggests that response-related inhibition does not contribute to distractor processing in auditory spatial negative priming. Interestingly, responding to the probe target location that previously contained the distractor in ignored repetition trials was not slowed down relative to response control trials when prime distractor and probe target sound matched. This result is uniquely predicted by the feature mismatching hypothesis of spatial negative priming (Park & Kanwisher, 1994) and cannot be explained by assuming a location- or response inhibition mechanism. The results of Experiment 1 further suggest that object file binding is a general coding principle even for to-be-ignored distractor events.

The absence of motor-related inhibition in this study is at odds with related findings in the visual modality (e.g., Buckolz et al., 2004; Fitzgeorge et al., 2011; Guy & Buckolz, 2007; Guy et al., 2006). Together with previous findings from auditory spatial negative priming tasks, the results of Experiment 1 might indicate modality-specific mechanisms of target selection in the presence of distractor information. It might be the case that inhibition operates on distractor responses in vision, but does not aid selection in auditory versions of the task. However, an alternative explanation for the absence of inhibitory after-effects in auditory spatial negative priming is considered in Experiment 2.

Experiment 2[3]

Experiment 2 tested whether the absence of evidence for inhibitory processing in previous studies of auditory spatial negative priming (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014, as well as in Experiment 1 of the present thesis) was due to an inappropriate timing of the prime-probe sequence. Note that, following the rationale of the spatial negative priming paradigm, processing of irrelevant prime events is

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[3] For details, see Möller, M., Mayr, S., & Buchner, A. (2015). The time-course of distractor processing in auditory spatial negative priming. *Manuscript submitted for publication*.

deduced from its impact on responding in the following probe. The spatial negative priming effect is, by definition, an after-effect. In this vein, several studies beyond the spatial negative priming suggest that the occurrence of inhibitory after-effects is strongly affected by the timing of distractor and target events (e.g., Bermeitinger, 2013; Lupiáñez & Solano, 1997; Machado, Guiney, & Struthers, 2013; Machado, Wyatt, Devine, & Knight, 2007; Maetens, Henderickx, & Soetens, 2009). With respect to spatial negative priming in audition, it might be possible that distractor events are actually inhibited during the prime processing, but no after-effect is measured at the time of the probe.

In vision, the impact of the timing of prime-probe sequence on spatial negative priming has been recently investigated by Buckolz, Avramidis, and Fitzgeorge (2008, Experiment 1). The authors examined the time-course of response-related inhibition in a visuospatial negative priming task by systematically setting the *response-stimulus interval* (RSI) between the prime response and the onset of the subsequent probe presentation to 2, 5, or 10 seconds[4]. The RSI manipulation affected the size of the spatial negative priming effect: Although a spatial negative priming effect was found for all RSI levels, it was reliably larger when prime response and probe onset were separated by 2 seconds as compared with an RSI of 5 and 10 seconds which, in turn, produced effects of equal size. In Experiment 2 of Buckolz et al. (2008), prime presentations always comprised either a single target or distractor stimulus while target and distractor stimuli were simultaneously presented in the corresponding probe. The offset of the prime stimulus and the onset of the following probe stimuli was blockwise separated by either 75 ms or 750 ms. Results revealed a typical visuospatial negative priming effect in the 750 ms condition. Interestingly, performance in ignored repetition trials was facilitated as compared with control trials when prime and probe events were separated by 75 ms.

In sum, the results of Buckolz et al. (2008) indicate two crucial temporal characteristics of response-related inhibition in visuospatial negative priming: First, the results of Experiment 2 show that response inhibition takes more than 75 ms to develop up to a level that impairs subsequent probe responding. More importantly, the decreas-

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[4] It has to be noted that Buckolz et al. (2008) employed three prime trial types in Experiment 1. In different blocks, the prime presentation either comprised (1) only a distractor, (2) a target event *or* a distractor event, or (3) the simultaneous presentation of target and distractor events. Therefore, the described effects of the RSI manipulation refer to the results from prime trial type (3) in which a prime response was required in the presence of a distractor event.

ing visuospatial negative priming effect with intervals of 5 seconds or longer in Experiment 1 indicates that the inhibitory status of a distractor response diminishes over time (see also Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991).

Turning to spatial negative priming in audition, all previous studies employed an RSI of 1,500 ms between the execution of the prime target response and the onset of the corresponding probe sound presentation (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014). Given the proposed dynamics of inhibition (Buckolz et al., 2008; Tipper et al., 1991), it might have been the case that (1) inhibition had not yet been sufficiently applied to the prime distractor or that (2) inhibition had already dissipated at the time the specific probe response was required. If the prime distractor response or location was either not yet or no longer sufficiently suppressed, probe performance in ignored repetitions trials cannot be impaired as compared with control trials, so that no spatial negative priming effect in audition emerged.

It is thus unclear whether inhibition does not operate in the auditory modality at all or whether the specific timing of prime and probe events was not suitable to detect the occurrence of spatial negative priming effects in auditory versions of the task. Experiment 2 was designed to decide between these two alternatives. To this end, the auditory spatial negative priming experiment of Mayr et al. (2011) was conceptually replicated with three experimental groups that systematically differed with respect to the RSI between prime response and onset of the probe sound presentation (600 ms, 1,250 ms, and 1,900 ms). In the ignored repetition subdesign, performance in *sound-repeated, location-repeated* trials as well as in *sound-changed, location-repeated* and *sound-repeated, location-changed* trials was compared with *sound-changed, location-changed* control trials, respectively. Given that previous studies did not find evidence of inhibition with an RSI of 1,500 ms, the predictions for the three different RSI groups were as follows: If inhibition is actually applied to the prime distractor location or its assigned response in audition, but the inhibitory status does not endure an interval of 1,500 ms, performance in *sound-changed, location-repeated* trials and *sound-repeated, location-repeated* trials should be impaired in the 600-ms RSI group and possibly in the 1,250-ms RSI group. However, no after-effects of inhibition should be present in the 1,900-ms RSI group. As a consequence, emerging inhibitory after-effects should decrease as the RSI increases. In contrast, if distractor inhibition takes more than 1,500 ms to sufficiently suppress spatial or response information associated with the prime distractor, performance in the critical *sound-changed, location-repeated* trials and *sound-repeated, location-repeated* trials should be impaired in the 1,900-ms RSI group, but not in the 600-ms and 1,250-ms RSI group. Therefore, inhibitory after-effects should increase with increasing RSIs.

The latency and accuracy results for the ignored repetition subdesign are shown in Figure 2. In contrast to the related findings in the visual modality (e.g., Buckolz et al., 2008), the pattern of results did not differ among the respective RSI groups. Most important, presenting the probe target from the speaker that emitted the former prime distractor did not generally impair responding. Performance was solely determined by the occurrence of feature mismatches for all RSI groups: Responding to probe targets was delayed in *sound-changed, location-repeated* as well as in *sound-repeated, location-changed* trials, while performance in *sound-repeated, location-repeated* trials did not differ from control trials.

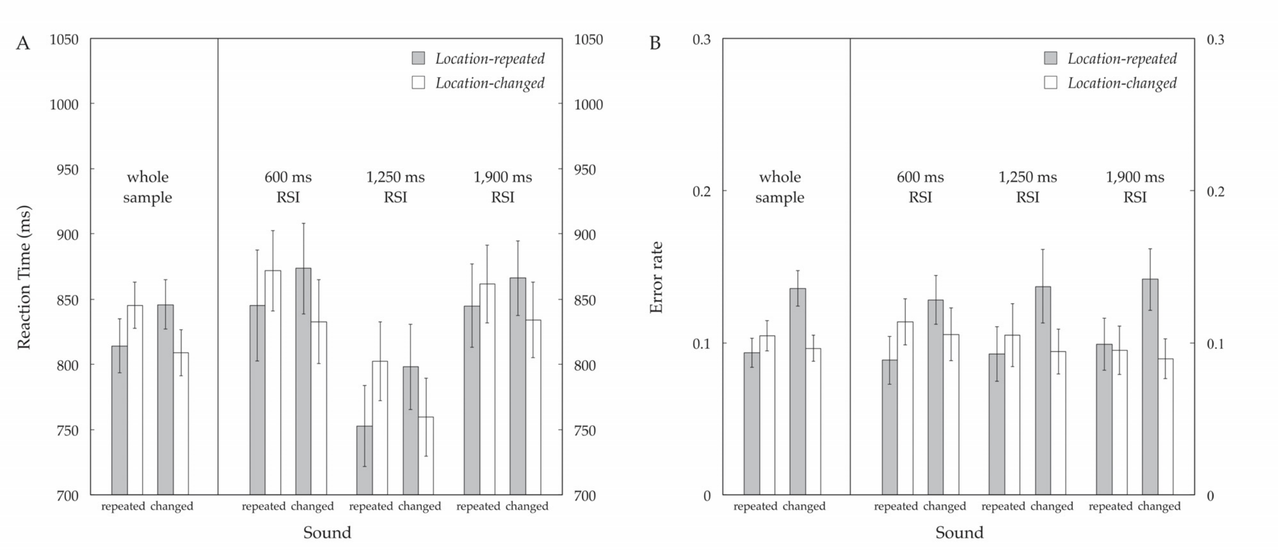

Figure 2: Mean reaction times (A) and error rates (B) for the three RSI groups (600 ms vs. 1,250 ms vs. 1,900 ms) and the whole sample as a function of location repetition (repeated vs. changed) and sound repetition (repeated vs. changed) in the ignored repetition subdesign of Experiment 2. The error bars depict the standard errors of the means.

In sum, the findings of Experiment 2 refute the assumption that the timing of prime-probe sequences of previous studies was inappropriate to detect after-effects of inhibitory processing. Instead, performance in all groups fully conformed to the predictions of the feature mismatching hypothesis (Park & Kanwisher, 1994). Therefore, the results of Experiment 2 are most easily explained by assuming that inhibition does not aid selection in auditory spatial negative priming. The reliable finding of feature mismatching effects in all RSI groups supplements the notion that object files are generated for task-irrelevant sound events and a time-consuming updating process prolongs responding in the case of feature mismatches between successive presentations. Moreover, the results of Experiment 2 give first insight into the persistence of object files in the auditory modality. Specifically, the results suggest that object files are promptly generated during prime processing and can be immediately retrieved. Furthermore, object files can be maintained in short-term memory for at least 1,900 ms after the prime response has been given. Together, the present findings suggest that response-related inhibition is not part of auditory selection but is mainly achieved by object file binding.

However, the absence of after-effects indicating response inhibition might be explained by insufficient response activation to non-target events in previous auditory spatial negative priming tasks. Within the response-inhibition account (e.g., Buckolz et al., 2004), the activation of distractor-assigned responses is assumed to be followed by inhibition, impairing their subsequent execution. In this regard, converging evidence from different lines of research suggests that the activation of distractor-assigned motor responses is a prerequisite for inhibition to occur (Burle, Possamaï, Vidal, Bonnet, & Hasbroucq, 2002; Ridderinkhof, 2002; Schlaghecken & Eimer, 2002) and that the amount of inhibition devoted to a non-target event is positively related to its initial strength of activation (Grison & Strayer, 2001; Houghton, Tipper, Weaver, & Shore, 1996; Schuch, Bayliss, Klein, & Tipper, 2010; Wyatt & Machado, 2013). Therefore, the absence of any response-related inhibitory effects in the present data may result from reduced activation of (manual) responses by auditory distractors. Although inhibitory response processing generally occurs in audition, the response activation triggered by audiospatial distractors is too small to call for this mechanism. As a result, no after-effect of inhibition is found. This possibility was experimentally addressed in Experiment 3 and Experiment 4B of the present thesis.

Experiment 3[5]

As outlined in the discussion of Experiment 2, it might be argued that response-related inhibition is only engaged in auditory processing if distractor-assigned re-

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[5] For details, see Möller, M., Mayr, S., & Buchner, A. (2015). Effects of spatial response coding on distractor processing: Evidence from auditory spatial negative priming tasks with keypress, joystick, and head movement responses. *Attention, Perception, & Psychophysics, 77*(1), 293-310. doi: 10.3758/s13414-014-0760-x.

sponses sufficiently strive for the control of action. With respect to visual processing, there is ample behavioral and electrophysiological evidence that visual distractors are processed up to a level of response activation as demonstrated by paradigms beyond the spatial negative priming task such as the flanker and Simon task, as well as the negative compatibility task (Buckolz, O'Donnell, & McAuliffe, 1996; Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; De Jong, Liang, & Lauber, 1994; Eimer & Schlaghecken, 2003; Eimer, Schubö, & Schlaghecken, 2002; Eriksen, Coles, Morris, & O'Hara, 1985; Ridderinkhof, 2002; Smid, Mulder, & Mulder, 1990; Valle-Inclán & Redondo, 1998). In contrast to the visual modality, the question of distractor-related response activation (and therefore the question whether the conditions for the operation of response inhibition in auditory versions of the task are met) is unsettled in audition.

Solely the auditory version of the Simon task has provoked profound research activity, but provided controversial findings with respect to manual response activation triggered by spatially presented distractors (Buetti & Kerzel, 2008; Leuthold & Schröter, 2006; Simon, Hinrichs, & Craft, 1970; Simon & Small, 1969; Wascher, Schatz, Kuder, & Verleger, 2001; for a review of the Simon effect, see Simon, 1990). In a series of experiments, Wascher et al. (2001) employed a typical Simon task with visual and auditory stimuli. In essence, Wascher et al. found reliable Simon-effects—that is, faster responding when the task-irrelevant location of the stimulus corresponded to the side of the correct response, as compared with trials in which the irrelevant stimulus location and the response side were in opposition—in auditory and visual versions of the task. However, the supplemental analysis of electrophysiological data revealed considerable differences regarding the mechanisms underlying the effect. Whereas the electrophysiological data strongly indicated that the visual Simon effect is caused by direct activation of the motor response ipsilateral to the task-irrelevant location of the stimulus, a comparable activation was absent in the auditory task. Based on this discrepancy, the authors concluded that visuospatial stimuli directly activate their spatially corresponding manual responses, while auditory stimuli do not. In sum, the results of Wascher et al. suggest that manual keypress response in auditory spatial negative priming tasks might be insufficiently activated to call for an inhibitory mechanism.

Following the reasoning outlined by Wascher et al. (2001), direct motor activation might be considerably stronger for or even generally restricted to responses of highest compatibility with respect to stimulus modality and task requirements, linking manual responses and visuospatial stimuli (Wickens, Sandry, & Vidulich, 1983; Wickens, Vidulich, & Sandry-Garza, 1984) to achieve precise spatially directed manual responding like reaching or grasping (e.g., Crammond & Kalaska, 1994; Georgopoulos, 1997). Therefore, the link between spatial stimuli and concurrent manual response activation might be either stronger per se or easier to establish in visual as compared with auditory processing, leading to somewhat stronger activation of distractor responses in the former than in the latter case. However, the activation (and possibly the subsequent inhibition) of distractor-assigned responses—as measured in spatial negative priming tasks—might come into effect if spatially presented auditory stimuli are assigned to highly compatible responses. In this vein, Wiegand and Wascher (2007) argued that direct response activation occurs whenever stimuli and responses are encoded with respect to a common feature, for example, in terms of their location in space. Further, the authors proposed that stimulus and response codes overlap when spatially distributed stimuli require spatially directed movement responses such as operating the handle of a joystick, turning a steering wheel, or moving a hand to depress a button at a specific location. In line with this assumption, employing spatially directed responses led to direct response activation in tasks in which direct response activation is usually absent (see Buetti & Kerzel, 2008 and Wiegand & Wascher, 2007 for evidence from Simon tasks with auditory and vertically-aligned stimuli, respectively).

The results from Buetti and Kerzel (2008) strongly suggests that direct response activation to irrelevant auditory events can be achieved by employing spatially directed responses in the respective task setting. Experiment 3 was based on this finding and further investigated the operation of response-related inhibition in auditory spatial negative priming. The rationale was as follows: The high degree of correspondence between the spatial coding of directed responses and the spatial features of the sounds should lead to response activation by distractor sounds. If response inhibition occurs in auditory processing, distractor-related response activation should be inhibited to prevent the execution of the activated distractor response, rendering it less accessible for a certain period of time. Therefore, performance should be impaired when the probe target location requires the execution of the previously distractor-assigned response.

To this end, two response modes were employed in an auditory spatial negative priming task similar to the one used in Experiment 2 (see also Mayr et al., 2011, Experiment 1). In the *joystick* group, participants moved a joystick toward the speaker from which emitted the target sound while ignoring a distractor sound at another location, while participants in the *keypress* group indicated the location of the target sound by pressing an assigned response key. Joystick responses were chosen because they (1) comprise salient spatial features and are encoded in terms of their movement direction (e.g., Dittrich, Rothe, & Klauer, 2012) and (2) the directional coding of joystick movements overlaps with the way spatial sound sources are represented because the joystick has to be moved toward the speaker locations. The results obtained in the joystick group were compared with the results of the parallel keypress group to determine the influence of the response mode on the pattern of results in auditory spatial negative priming. Specifically, any evidence for response-related inhibition would result in delayed and potentially more-error-prone responding in *sound-repeated, location-repeated,* as well as in *sound-changed, location-repeated* trials as compared with *sound-changed, location-changed* control trials. The results for probe performance in the hypothesis-relevant trial types are shown for both response type groups in Figure 3.

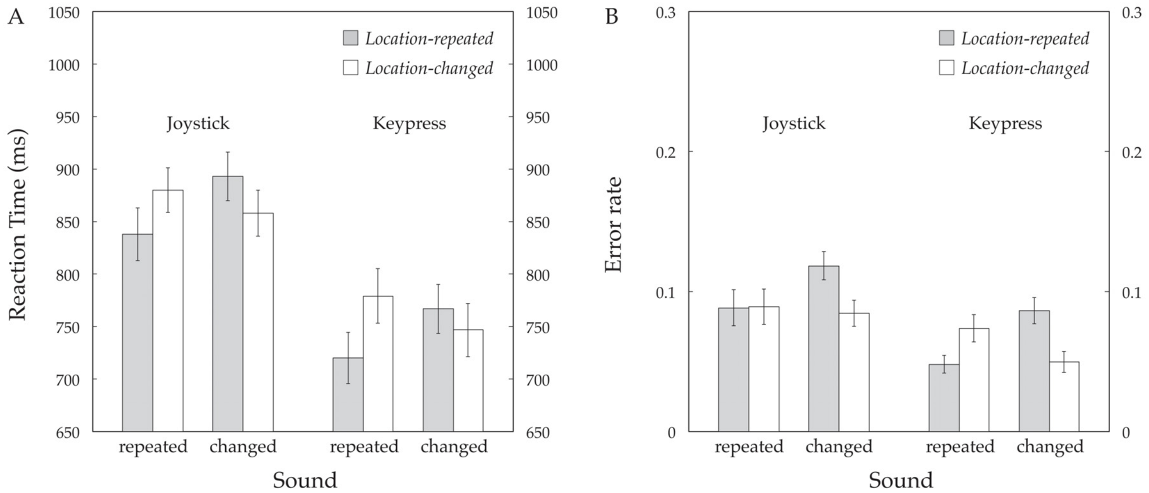

Figure 3: Mean reaction times (A) and error rates (B) for joystick and keypress responses as a function of location repetition (repeated vs. changed) and sound repetition (repeated vs. changed) in the ignored repetition subdesign. The error bars depict the standard errors of the means.

The results are straightforward: The results from both response types fully conformed to the predictions of the feature mismatching hypothesis in that performance in ignored repetition trials was only delayed when probe target and prime distractor mismatched with respect to their identity or their location in space (i.e., in *sound-changed, location-repeated* trials and in *sound-repeated, location-changed* trials, respectively). Instead, performance in *sound-repeated, location-repeated* trials was equal to control trials.

Two conclusions can be drawn from Experiment 3. First, the results of the keypress condition nicely replicate previous findings and underscore the strong impact of feature mismatching effects on performance in auditory versions of spatial negative priming tasks with similar responses (see Experiment 1 and 2 of the present thesis as well as Mayr et al., 2011, Experiment 1). Second and more important, feature mismatching effects exclusively determined performance in the joystick condition while no inhibitory after-effects emerged with spatially directed responses. Because the activation of distractor-related responses can be assumed for spatially directed joystick movements in the present task (e.g., Buetti & Kerzel, 2008; Wiegand & Wascher, 2007), responses to non-target locations should have been suppressed if an inhibitory mechanism prevents false responding in the auditory modality. Rather, the results can be taken as evidence that selection in auditory processing does not recruit an inhibitory process that suppresses distractor-assigned responses, at least not in a way that their subsequent execution is delayed. Moreover, evidence for feature mismatching effects was found in Experiment 3 despite the need to perform considerably different responses (i.e. spatially directed joystick movements or static keypress responses). This finding demonstrates that feature mismatching effects do not depend on the use of keypress responses in auditory spatial negative priming. This further strengthens the notion that of object file binding is a *general* coding principle in auditory processing.

Given that no evidence for response inhibition was found, the activation of joystick responses by irrelevant sounds might still be lower as compared with the response activation triggered by visual stimuli. This might be due to a presumably stronger link between spatial stimulus processing and manual responding in vision as compared with audition (e.g., Barfield, Cohen, & Rosenberg, 1997; Wascher et al., 2001; Wickens et al., 1983; Wickens et al., 1984). Despite the assumed overlap between the way joystick responses and sound locations are encoded in an auditory spatial negative priming task, depressing the joystick handle towards the target sound location still required a *manual* response in Experiment 3. Therefore, the presumably weaker link between manual responding and auditory processing (as compared with vision) might not have been fully compensated by a common spatial coding of responses and sound sources. As a consequence, responses to irrelevant sound sources might not be *sufficiently* activated to call for an inhibitory mechanism.

The goal of Experiment 4 was to further investigate whether distractor-related response activation and inhibition occurs in auditory processing. To this end, head movement responses were employed in two localization tasks because they entail a strong relationship to spatial processing in audition but do not involve the manual response system.

Experiments 4A and 4B

Experiment 4 employed head movement responses to maximize the strength of distractor related response activation and, in turn, the operation of response inhibition. Head movements can be regarded as ecologically valid motor responses to spatial sounds (e.g., Corneil & Munoz, 1996; Goldring, Dorris, Corneil, Ballantyne, & Munoz, 1996; Perrott, Saberi, Brown, & Strybel, 1990, for a review of psycho-acustical, physiological and experimental data, see Arnott & Alain, 2011) which are regarded as a presumably innate orientation reflex (Clifton, 1992).

Experiment 4 utilized prior evidence of distinct perceptuo-motor links between spatial sounds and head movements to further investigate response-related mechanisms underlying auditory spatial selection. Experiment 4A tested whether spatial parameters of head movement responses towards target locations were affected by the presence of an auditory distractor at another location. The rationale was as follows: If distractor sounds modify the way participants turn their heads towards the target sound sources, this would strongly imply that responses to irrelevant spatial sounds are indeed activated up to a level that affects temporal and spatial parameters of voluntary head movements. In other words, auditory distractor processing would not seem to stop at an early, possibly perceptual level, but would lead up to a (pre-)motor stage. Such a finding would be compatible with the notion of direct response activation in auditory processing and therefore fulfill the prerequisite for inhibition to apply.

Experiment 4A[6]

In Experiment 4A, participants had to turn their head towards the speaker that emitted the target sound (see the *Method* section of the respective publication for a detailed explanation of the measurement and the analysis of head movement directions in Experiment 4A and 4B, respectively). A visual cue indicated the to-be-attended sound and each trial comprised a single presentation. Latency, accuracy, and spatial parameters of head movements were compared between two trial types: In one half of the trials, a target and a distractor sound were simultaneously presented from two (out of four) speakers (*distractor present*). In the other half of the trials, the target sound occurred alone (*distractor absent*). Any influence of distractor events on spatial movement parameters would strengthen the notion that head movement responses towards irrelevant sounds were actually activated. Note that Experiment 4A was not concerned with any after-effects of distractor processing on subsequent responding. As a consequence, performance was solely assessed for single presentations (see Experiment 4B for use of head movement responses in an auditory spatial negative priming task). The results for latency and accuracy measures are shown in Figure 4.

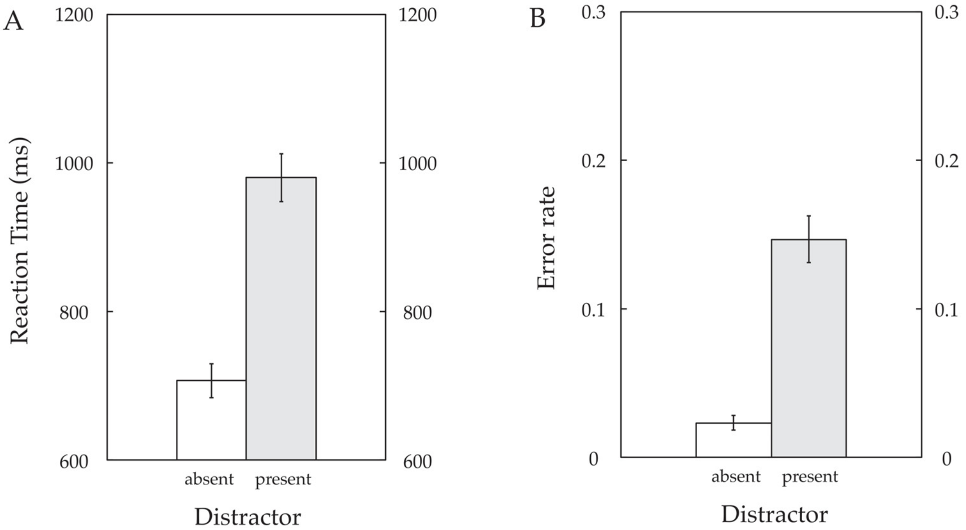

Figure 4: Mean reaction times (A) and error rates (B) for head movement responses as a function of distractor presence (absent vs. present). The error bars depict the standard errors of the means.

The presence of a simultaneous distractor reliably affected the latency and accuracy

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[6] For details, see Möller, M., Mayr, S., & Buchner, A. (2015). Effects of spatial response coding on distractor processing: Evidence from auditory spatial negative priming tasks with keypress, joystick, and head movement responses. *Attention, Perception, & Psychophysics, 77*(1), 293-310. doi: 10.3758/s13414-014-0760-x.

of head movement responses toward target locations. Specifically, head movement responses were slower and less accurate when a concurrent distractor was presented from another speaker. Most important, the analysis of the spatial parameters of head movements indicated that head movements to the target locations veered away from the location of the simultaneously presented distractor. Following action-based models of selective attention, a systematic movement deviation away from the distractor is typically interpreted as evidence for the inhibition of distractor-related response codes (e.g., Meegan & Tipper, 1998; Neyedli & Welsh, 2012; Tipper, Lortie, & Baylis, 1992; Welsh & Elliott, 2004; Welsh, Elliott, & Weeks, 1999; Welsh, Neyedli, & Tremblay, 2013). The results of Experiment 4A suggest that responses towards non-targets were activated and immediately inhibited, resulting in a distractor-evading head movement. This suggests that distractor processing up to the activation of corresponding responses is not limited to vision, but also occurs in the auditory modality (for related findings, see Buetti & Kerzel, 2008; Corneil & Munoz, 1996; Leuthold & Schröter, 2006). In the same vein, it can be further concluded that the suppression of distractor responses—as a mechanism to prevent false responding—operates in both modalities. Together, these findings suggest that distractor processing does not fundamentally differ between the visual and auditory modality.

Experiment 4B[7]

Given the results of Experiment 4A, head movements were used in an auditory spatial negative priming task to determine the consequences of response-related inhibition on future processing. In Experiment 4B, half of the participants indicated the location of one of two simultaneous sounds by manually pressing an assigned key on a response box while the remaining half responded by turning their head towards the respective sound source. If distractor-related response inhibition with highly compatible head movement responses affects performance in the subsequent trial, performance should be impaired in trials which require the execution of the former distractor-response at the time of the probe, leading to prolonged responding and lower accuracy in *sound-changed, location-repeated* trials, as well as in *sound-repeated, location-repeated* trials compared to their respective control. In contrast, responding in *sound-*

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[7] For details, see Möller, M., Mayr, S., & Buchner, A. (2015). Effects of spatial response coding on distractor processing: Evidence from auditory spatial negative priming tasks with keypress, joystick, and head movement responses. *Attention, Perception, & Psychophysics, 77*(1), 293-310. doi: 10.3758/s13414-014-0760-x.

repeated, location-changed trials should not be affected because no response repetition occurs between prime distractor and probe target. The results of Experiment 4B are shown in Figure 5.

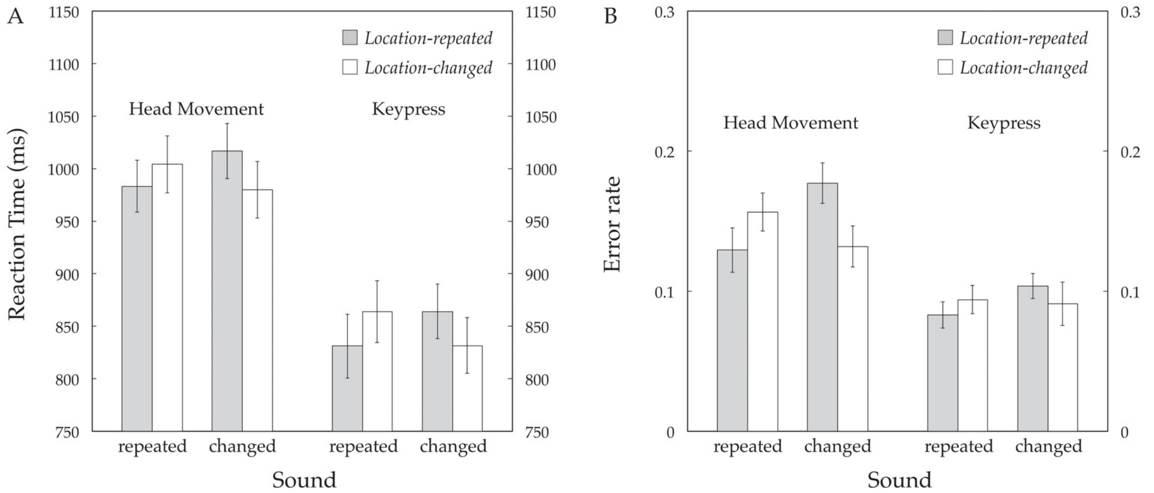

Figure 5: Mean reaction times (A) and error rates (B) for head movement and keypress responses as a function of location repetition (repeated vs. changed) and sound repetition (repeated vs. changed) in the ignored repetition subdesign. The error bars depict the standard errors of the means.

As expected, performance in the keypress group revealed a pattern of performance compatible with the feature mismatching hypothesis (Park & Kanwisher, 1994). However, executing a previously distractor-assigned head movement toward the probe target was not generally slowed-down as compared with control trials. This finding is surprising, given that Experiment 4A provided evidence that head movements toward non-target sounds are activated and subsequently inhibited. Moreover, performance in the head movement group was solely determined by the occurrence of features mismatches. In sum, Experiment 4A provided experimental evidence for the operation of response-related inhibition for head movement responses in auditory-spatial selection tasks, while no after-effect of inhibitory distractor processing was found in Experiment 4B. Instead, feature mismatching effects determined probe responding in Experiment 4B. Therefore, the results of Experiment 4B are informative with respect to the time-course of inhibitory after-effects in auditory processing. Specifically, the results are well in line with the notion that response-related inhibition had already dissipated at the time of the probe so that responding was not hampered. Specifically, the results of Experiment 4B suggest that inhibition triggered by auditory spatial stimuli does not endure an interval of 1,700 ms, thereby differing from related findings in the visual modality (Buckolz, Edgar, et al., 2012;

Guy & Buckolz, 2007). The different time courses of response inhibition in visual and auditory processing might be explained by assuming that the persistence of inhibition in both modalities is also determined by its initial strength. As mentioned above, the amount of inhibition devoted to a non-target event is, in turn, determined by the strength of distractor activation (e.g., Grison & Strayer, 2001; Houghton et al., 1996; Schuch et al., 2010; Wyatt & Machado, 2013). Therefore, it might be argued that although head movement responses were sufficiently activated to call for an inhibitory mechanism (as indicated by Experiment 4A), the strength of the resulting inhibition was lower as compared with corresponding processing in vision. This argument receives plausibility by the presumably weaker link between stimulus and response processing in audition than in vision (Barfield et al., 1997; Wascher et al., 2001; Wickens et al., 1983; Wickens et al., 1984). In audition, the presumably smaller amount of distractor-related activation leads to an amount of inhibition that does not persist through the interval of 1,700 ms between prime response and probe sound presentation (Experiment 4B), while the high level of inhibition triggered by distractors in related visual tasks does.

Conclusion and Outlook

The aim of the present series of experiments was to extend the knowledge about the specific mechanisms of selection in auditory processing and to test theories explaining spatial negative priming in audition. Previous reports of spatial negative priming indicated modality-specific mechanisms of selection. While all previous studies indicated that feature mismatching effects are the sole determinant of auditory spatial negative priming (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014), no evidence for the inhibition of responses assigned to non-target locations has been found. This served as a starting point for the present experiments. Five experiments were conducted to address the question whether the absence of inhibitory after-effects in auditory spatial negative priming indicates modality-specific mechanisms of distractor processing or can be rather attributed to the specific task settings employed in previous studies of auditory spatial negative priming.

In the following, the contribution of each experiment is shortly summarized. Experiment 1 disentangled the contribution of response and location repetition on performance in auditory spatial negative priming. The result showed that the need to execute a previously withheld response does not impair its subsequent execution, thereby challenging the response inhibition account of spatial negative priming (e.g., Buckolz et al., 2004). Moreover, performance in traditional ignored repetition trials was strongly influenced by the occurrence of feature mismatches. Experiment 2 investigated whether evidence for inhibitory distractor processing had been absent in prior studies due to an inappropriate timing of events. In contrast to this assumption, Experiment 2 revealed no evidence for inhibitory distractor processing—in terms of a spatial negative priming effect—with RSIs shorter (600 ms, 1,250 ms) or longer (1,900 ms) than the RSI of 1,500 ms previously used in auditory spatial negative priming tasks (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014). Instead, performance in all groups fully conformed to the predictions of the traditional feature mismatching hypothesis (Park & Kanwisher, 1994) and its recent extension proposed by Mayr et al. (2011). Finally, Experiments 3 and 4 maximized response activation toward non-target sound sources which is assumed to be a prerequisite for inhibitory distractor processing. To this end, Experiment 3 used spatially directed joystick responses while Experiment 4B required participants to perform head movement responses toward target sounds in auditory spatial negative priming tasks. Experiment 4A assessed the effect of a concurrent distractor on head movements towards target locations. Experiments 3 and 4B did not find evidence for inhibitory distractor processing but conformed to the feature mismatching hypothesis (Park & Kanwisher, 1994). Interestingly, the analysis of the spatial parameters of head movement responses in Experiment 4A indicated that responses towards target sound sources veered away from the location of the concurrent distractor. This may be taken as evidence that distractor sound locations were activated and immediately inhibited. Despite the independent evidence that spatially directed responses are automatically activated (e.g., Buetti & Kerzel, 2008; Wiegand & Wascher, 2007) and inhibited (see Experiment 4A of the present thesis) by spatial sounds, distractor response inhibition did not affect subsequent performance in Experiment 4B. The absence of inhibitory after-effects in Experiment 4B is attributed to the rapid decay of response-related inhibition triggered by audiospatial distractor events that does not endure an RSI of 1,700 ms.

In sum, all results from the current auditory spatial negative priming tasks are readily explained by the feature mismatching hypothesis (Park & Kanwisher, 1994). This supplements the importance of object file binding for relevant and irrelevant sound events in auditory selection. Moreover, Experiment 4A provides first evidence for distractor response inhibition in auditory processing. The results of Experiment 4A therefore refute the conclusion that inhibition does not operate in audition. Instead, goal-directed behavior seems (at least partly) governed by the same mechanisms in vision and audition. In this vein, the present results are in line with the notion that the occurrence of distractor response inhibition critically depends on the degree of initial response activation to non-target events. When distractor responses are sufficiently activated (e.g., by employing compatible responses to spatially presented stimuli) response-related inhibition is triggered by visual as well as auditory distractors. Moreover, the present experiments provide new knowledge about the time course of distractor processing. With respect to the persistence of feature mismatching effects, the results of Experiment 2 suggest that object files are immediately available after prime processing and endure an interval of at least 1,900 ms. Instead, Experiment 4B suggests that the inhibition of head movement responses is short-lived, so that no after-effect of inhibition is measured with an RSI of 1,700 ms.

It has to be noted that the present Experiment 4A is first to provide evidence for response inhibition in auditory processing. Therefore, any conclusions concerning the characteristics of response inhibition in audition can only be preliminary and demand further research. For example, Experiment 4B may be interpreted to indicate that response-related inhibition is fully decayed after an RSI of 1,700 ms which directly raises the question of the time course of response inhibition in audition. Subsequent studies might employ RSIs shorter than 1,700 ms in a paradigm comparable to the one used in Experiment 4B. This would allow to determine the specific timing of the proposed activation-inhibition sequence for distractor responses (for a related approach in visuospatial negative priming, see Buckolz et al., 2008). The finding of facilitated responding with the previous distractor response at short RSIs that turns into a disadvantage at longer RSIs would support the proposed similarity between visual and auditory distractor processing. With respect to the time course of inhibition, the absence of inhibitory after-effects in Experiment 1-3 is presumably due to the insufficient activation of manual keypress responses by irrelevant spatial sounds. However, it might be argued that inhibition generally occurs with manual responses, but requires even more than 1,900 ms (the longest RSI employed in Experiment 2) to accrue before subsequent responding is affected. Although this alternative explanation cannot be directly excluded based on the present results, it is contradicted by preliminary data from a recent study by our group. Specifically, the study replicated Experiment 2 of the present thesis with RSIs of either 2,500 ms, 3,500 ms, or 4,500 ms. In short, the results support the feature mismatching hypothesis and no evidence for distractor inhibition occurred for all RSIs. Therefore, within the range of RSIs tested, a slow accumulation of response-related inhibition with keypress responses seems rather unlikely.

The analysis of spatial parameters in Experiment 4A has been proven useful in assessing inhibitory distractor processing in audition. However, Experiment 4A did not explicitly investigate the impact of prime-to-probe repetitions on spatial parameters of head movement responses. It might be the case that spatial parameters of target-directed movements are more sensitive measures of inhibitory after-effects as compared with response times and accuracy measures. Therefore, it might be useful to analyze movement directions in an auditory spatial negative priming task. Specifically, the movement direction towards a relevant sound source in the probe might be systematically affected by spatial parameters of the previously withheld response.

This broad evidence for object file binding for distractors raises the question whether this mechanism contributes to *selection* in the sense that it operates to disentangle relevant and irrelevant aspects contained in a concurrently presented stream of information. With respect to the findings reported here, Experiment 2 provides tentative evidence that object file binding occurs as part of the selection process. This is because effects of object file retrieval have been observed as early as 600 ms after the prime response in Experiment 2. This is well in line with the notion that object files are generated for target and distractor sounds to disentangle relevant and irrelevant aspects interwoven in the conjoint signal of concurrently presented sounds. After spatial and sound identity features are bound into a common representation, the object file associated with the currently task-defined target is further processed and ultimately translated into a response. The relation between object file binding and selection has been recently investigated by Mayr et al. (2014, Experiment 2). They employed an auditory spatial negative priming task similar to the one used in Experiment 2, but varied the modality of the cue in the prime. Half of the trials comprised a visual cue displaying a picture of the to-be-attended instrumental sound, while in the other half the specific sound was presented as cue. The probe always comprised a visual cue. With visual prime cues, Mayr et al. found typical feature mismatching effects on probe responding. However, probe performance in ignored repetition trials was not affected at all by location or identity repetitions between prime distractor and probe target when the to-be-attended instrumental sound was indicated by an auditory cue in the prime and a visual cue in the probe presentation. This was taken as evidence that object file binding for non-target events is not a mandatory characteristic of auditory processing, but depends on the processing demands in the task. Following the authors, object file binding does not occur and, consequentially, feature mismatching effects are absent, when the target sound can be separated from a concurrent distractor on the basis of spectro-temporal cues (e.g., Hawley, Litovsky, & Culling, 2004; Noble & Perrett, 2002). However, this finding suggests that object file binding *is* a mechanism of selection when the target cannot be directly processed.

Two main conclusions can be drawn from the present series of experiments: First, the findings strengthen the importance of object file binding as a mechanism of selection in auditory spatial negative priming. Moreover, first evidence for response-related inhibition is provided in an auditory selection task. Therefore, it might be concluded that these mechanisms are not mutually exclusive, but both contribute (to a different degree) to goal-directed behavior in audition. This dual mechanism predominantly entails the generation of object files for target and distractor events which is complemented by response inhibition when distractor-assigned responses actually strive for the control of action.

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Publications and Manuscripts

Experiment 1

Möller, M., Mayr, S., & Buchner, A. (2013). Target localization among concurrent sound sources: No evidence for the inhibition of previous distractor responses. *Attention, Perception, & Psychophysics, 75*(1), 132-144. doi: 10.3758/s13414-012-0380-2.

Experiment 2

Möller, M., Mayr, S., & Buchner, A. (2015). The time-course of distractor processing in auditory spatial negative priming. *Manuscript submitted for publication*.

Experiment 3, 4A, 4B

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Target localization among concurrent sound sources: No evidence for the inhibition of previous distractor responses

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Abstract The visuospatial negative priming effect—that is, the slowed-down responding to a previously ignored location—is partly due to response inhibition associated with the previously ignored location (Buckolz, Goldfarb, & Khan, Perception & Psychophysics 66:837-845 2004). We tested whether response inhibition underlies spatial negative priming in the auditory modality as well. Eighty participants localized a target sound while ignoring a simultaneous distractor sound at another location. Eight possible sound locations were arranged in a semicircle around the participant. Pairs of adjacent locations were associated with the same response. On *ignored repetition* trials, the probe target sound was played from the same location as the previously ignored prime sound. On *response control* trials, prime distractor and probe target were played from different locations but were associated with the same response. On *control* trials, prime distractor and probe target shared neither location nor response. A response inhibition account predicts slowed-down responding when the response associated with the prime distractor has to be executed in the probe. There was no evidence of response inhibition in audition. Instead, the negative priming effect depended on whether the sound at the repeatedly occupied location changed identity between prime and probe. The latter result replicates earlier findings and supports the feature mismatching hypothesis, while the former is compatible with the assumption that response inhibition is irrelevant in auditory spatial attention.

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Responding to the identity of a stimulus that was ignored in a previous presentation is overall slowed down—and often more error prone—than responding to a stimulus that was not part of a previous presentation. This phenomenon, termed the identity negative priming effect, is widely used to study mechanisms of selective attention and memory that allow goal-directed behavior in multistimulus environments (for reviews, see Fox, 1995; Mayr & Buchner, 2007; Tipper, 2001). Identity negative priming is typically investigated by simultaneously presenting target and distractor stimuli that have to be distinguished on the basis of a feature such as color. A response is based on the identity of the stimulus.

In the spatial variant of the negative priming task, participants are required to locate a predefined target in the presence of a distractor. On *ignored repetition* trials, the probe target is presented at the spatial location of the previous prime distractor. On *control* trials, there is no repetition of stimulus locations between successive prime–probe trials. Typically, ignored repetition trials result in prolonged response times, as compared with control trials, constituting the spatial negative priming effect (Chao, 2009; Milliken, Tipper, & Weaver, 1994; Tipper, Brehaut, & Driver, 1990), while accuracy is not necessarily impaired (Christie & Klein, 2008; Fitzgeorge & Buckolz, 2008; Guy, Buckolz, & Pratt, 2004). The spatial negative priming paradigm serves as a useful instrument for identifying how the cognitive system deals with objects appearing at to-be-ignored locations while attention is focused on task-relevant information at other positions in space. The explanations of the spatial negative priming effect resemble those accounts that have been put forward to explain identity-based negative priming: The inhibition account posits that the spatial representation of distractors is selectively inhibited (Milliken, Tipper, Houghton, & Lupiáñez, 2000; Tipper et al., 1990). Alternatively, the episodic retrieval account posits that the retrieval of prime episodes is triggered by presenting a probe target at the location of the prime distractor (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992), which serves as a retrieval cue to the prime episode. Retrieved prime episodes contain the information that no response was executed to objects at the distractor location.

Recently, a study by Buckolz, Goldfarb, and Khan (2004) expanded the discussion about the processes underlying the selection of target stimuli in the presence of simultaneous distractors by proposing a motor-related cause of the spatial negative priming effect. The authors argued that, in a typical spatial negative priming task, each location is mapped onto a discrete response. On ignored repetition trials, a response has to be executed that was assigned to the distractor in the previous trial. It was proposed that negative priming is not the aftereffect of previously ignoring a stimulus location but stems from the requirement to execute a previously suppressed motor response on ignored repetition trials. According to Buckolz et al. (2004), simultaneously presenting target and distractor stimuli in the prime leads to an automatic activation of both their assigned responses. This initial activation is thought to be followed by the inhibition of the distractor-assigned motor response in order to counteract a response conflict in favor of the required target response. It is important to note that spatial negative priming has been repeatedly observed for trials without a prime target, implying no overt prime response (e.g., Buckolz, Avramidis, & Fitzgeorge, 2008; Milliken et al., 2000). In this case, a *conflict* is thought to arise in the prime between the activation of the distractor-assigned response and the need to withhold this specific response, rather than between the activated target and distractor responses. In both cases—that is, in situations with and in situations without a prime target and a prime response requirement—the residual inhibition of the former distractor response prolongs its execution as the correct probe response on ignored repetition trials. In the following, the term *conflict* is used for all situations in which an activated response is not in accord with the correct response requirement. This response-based explanation is corroborated by electrophysiological and behavioral evidence of automatic response activation and subsequent inhibition of distractor-related motor responses in similar experimental paradigms such as the well-known flanker and Simon tasks (Buckolz, O'Donnell, & McAuliffe, 1996; Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; De Jong, Liang, & Lauber, 1994; Eriksen, Coles, Morris, & O'Hara, 1985; Ridderinkhof, 2002; Smid, Mulder, & Mulder, 1990; Valle-Inclán & Redondo, 1998), as well as the negative compatibility task where the to-be-executed response was recently activated by a masked prime and, thus, had to be inhibited (Eimer, 1999; Eimer, Schubö, & Schlaghecken, 2002).

To test the response inhibition account of spatial negative priming, Buckolz et al. (2004; for replications, see Fitzgeorge, Buckolz, & Khan, 2011; Guy & Buckolz, 2007; Guy, Buckolz, & Khan, 2006) isolated the influence of reexecuting a previously irrelevant response in a spatial negative priming task by modifying the location–response assignment. Participants had to locate a dark blue rectangle by manually pressing a location-assigned response key while ignoring a light blue distractor rectangle. The two stimuli were presented in two out of five horizontally aligned display locations. The two left and the two right locations were each mapped onto distinct spatially compatible response keys. When a target stimulus appeared at the center location, participants were free to choose one of the two keys that were assigned to the two adjacent locations. With this assignment, reexecuting a prime distractor response in the probe could take place without presenting the probe target at the former prime distractor location: Presenting a prime distractor stimulus at the center location was assumed to result in an automatic activation and subsequent inhibition of both responses associated with the center location, making these responses less available in the following probe.[1] Execution of the inhibited responses could be probed by presenting the probe target at one of the two adjacent locations (assigned to the same response). This resulted in so-called *response control* trials, in which the withheld prime response had to be executed in the probe trial without location repetition between the prime and probe presentations. Response times were compared among response control trials, traditional ignored repetition trials in which a response repetition was always accompanied by a location repetition, and control trials without location and response repetition between prime and probe. The results showed that responses on response control and ignored repetition trials were slowed down, in comparison with control trials. This pattern of results suggests a response locus of spatial negative priming because response repetition, rather than location repetition, was crucial for finding a slowdown in responding. As an additional finding, reaction times were significantly longer on response control trials than in ignored repetition trials. Following Buckolz et al.'s (2004) argumentation, the latter result indicates that prime distractor-to-probe target location repetitions actually facilitate stimulus processing. Overall, Buckolz et al.'s (2004) findings suggest that response-based inhibition can be the sole cause of the spatial negative priming effect, which stands in contrast to the widespread assumption of location-based inhibition as the underlying mechanism.[2]

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[1] Note that the same rationale would also hold if not both but only one of the two distractor-assigned responses were activated and subsequently inhibited during the prime presentation of response control trials. However, see Buckolz et al. (2004) for evidence of response activation and subsequent inhibition of both responses.

[2] Note that the influence of response inhibition can only be unambiguously assessed with centrally presented stimuli. For parafoveal stimuli, a potential response inhibition mechanism would possibly come along with an additional mechanism producing an inhibition-of-return effect (e.g., Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Davies, & Lauder, 2006).

Until recently, investigations of the spatial negative priming effect were restricted to the visual modality, although the auditory system is frequently concerned with focusing on sounds from a distinct location in space in the presence of interfering sounds from different directions. There are numerous differences between audition and vision in basic stimulus processing, perceptual organization, and the availability of peripheral information to aid selection (Banks, Roberts, & Ciranni, 1995). Therefore, employing the spatial negative priming paradigm permits further insight into the particular mechanisms underlying spatial selective attention in audition. Only two recent studies have examined spatial negative priming in audition. In the study of Mayr, Hauke, and Buchner (2009), participants had to locate one of two simultaneous sounds (piano, crow), originating from two (out of four) different and easily discriminable loudspeaker positions. The identity of the target sound was indicated by a visual cue preceding the auditory presentation. On ignored repetition trials, the probe target sound was presented from the loudspeaker from which the prime distractor had just been presented. On control trials, there was no location repetition between successive presentations. In addition, the sound identity of prime distractor and probe target was manipulated. On ignored repetition *match* trials, prime distractor and probe target were identical sounds. On ignored repetition *mismatch* trials, prime distractor and probe target were different sounds. Responses to sounds at previously ignored locations were not generally slowed down. Instead, the negative priming effect was modulated by the match/mismatch manipulation: Prolonged response times were found only on ignored repetition trials with a sound mismatch at the repeated location, whereas response times on match trials did not differ from the response times in the control condition. This result cannot be explained completely by inhibition of ignored locations during the prime or by retrieval of probe-incompatible prime episode information associated with the ignored location. Instead, it supports the so-called feature mismatching hypothesis of spatial negative priming (see Mayr, Buchner, Möller, & Hauke, 2011, for a replication).

The feature mismatching hypothesis was originally put forward by Park and Kanwisher (1994) to explain the visuospatial negative priming effect. In essence, slowed-down responses to previously ignored locations are assumed to derive from changing features at repeated locations between the prime and probe presentations. According to the feature mismatching hypothesis, stimulus identities and their spatial locations are bound into *object files* (Kahneman, Treisman, & Gibbs, 1992), irrespective of their status as target or distractor on the current trial. Identical repetitions of a stimulus are assumed to yield reduced response times and error rates, whereas stimulus changes between prime and probe are associated with a cost in latency and accuracy. Park and Kanwisher argued that on ignored repetition trials, feature mismatches occur by default. This is so because target and distractor identities usually remain constant across trials. If, for example, participants respond to the location of a target stimulus (e.g., “@”) while ignoring a distractor stimulus (e.g., “+”) at a different location in the prime, the probe target stimulus “@” appears at the location of the prime distractor “+” to establish an ignored repetition trial. The location repetition is therefore inevitably accompanied by a feature mismatch, rendering the feature mismatching hypothesis a valid alternative explanation of visuospatial negative priming. Park and Kanwisher (Experiment 4) demonstrated the absence of a negative priming effect for trials without a feature mismatch by reversing target and distractor identities from prime to probe (while participants were required to localize a symbol “X” and ignore a symbol “O” during the prime, they had to localize the “O” and to ignore the “X” in the subsequent probe presentation, resulting in ignored repetition trials without a feature mismatch). Although the contribution of feature mismatching on visuospatial negative priming was initially demonstrated by Park and Kanwisher, the majority of later studies demonstrated a visuospatial negative priming effect in the absence of feature mismatches. This led to the conclusion that the feature mismatching hypothesis can be excluded as the main explanation of negative priming in vision (Milliken et al., 2000; Milliken et al., 1994; Tipper, Weaver, & Milliken, 1995).

In audition, in contrast, feature mismatching *can* explain why reactions to previously ignored locations are slowed down (Mayr et al., 2011; Mayr et al., 2009). However, it is not clear whether response inhibition also contributes to this slowdown. This is so because, just as in visual spatial negative priming tasks, repetitions of the ignored prime location as the probe target location also involves a repetition of the response. The aim of the present study thus was to test whether distractor-related response inhibition contributes to spatial negative priming in audition. To this end, the present study was designed to isolate the influence of reexecuting a response that had been assigned to the previous prime distractor from the influence of responding to a sound at a previously ignored location. In analogy to Buckolz et al. (2004), we used a many-to-one location–response mapping with eight possible sound locations, of which pairs of two were assigned the same response. This 8:4 location–response mapping made it possible to generate (1) trials with location and response repetitions between prime distractor and probe target (ignored repetition trials), (2) trials with response repetitions but no location repetitions between prime distractor and probe target (response control trials), and (3) trials devoid of any response or location repetitions (control trials).

Hypothesis testing was based on two crucial trial type comparisons: the comparison between response control and control trials, as well as the comparison between ignored repetition and response control trials. If automatic response activation followed by response inhibition takes place for auditory distractors, responding on response control trials should be impaired, as compared with control trials. The standard negative priming effect (i.e., the comparison between ignored repetition and control trials) was also calculated and tested, but note that this effect is equivocal with respect to the underlying mechanism(s) because it confounds response and location repetition effects. Given that preceding studies of auditory spatial negative priming (Mayr et al., 2011; Mayr et al., 2009) supported a feature mismatching explanation, the predictions of the response inhibition account were directly pitted against the feature mismatching account. This was done by including sound repetition (repeated vs. changed) between prime distractor and probe target as an additional experimental variable. It was thus possible to compare performance in ignored repetition trials with and without a feature mismatch. The feature mismatching hypothesis predicts that responding on ignored repetition trials will be slowed down, as compared with their respective control trials, only in the case of a sound change at the repeated location. In contrast, response times on ignored repetition trials containing sound repetitions should be equal to, or even shorter than, response times on the respective control trials. Following the feature mismatching account, both types of response control trials (i.e., sound-repeated and sound-changed trials) should yield response times comparable to those on their respective control trials, since there is no location repetition and, hence, no feature (mis)match on response control trials.

Method

Participants

Five out of 85 participants did not reach the learning criterion in either the first or the second training phase (see below), resulting in a total sample of 80 adults (51 females) ranging in age from 19 to 40 years (M = 24). Participants were tested individually and either were paid or received course credit.

Materials

Four easily discriminable instrumental sounds (guitar, drum, triangle, harmonica) were digitally recorded at a rate of 48 kHz, subsequently cut to a length of 400 ms (10-ms linear onset–offset ramps), and normalized to have identical RMS energy. All sounds were presented at an intensity of approximately 64 dB(A) SPL. Participants sat in the middle of a 2.5 × 3.5 m room with their head placed on a chinrest, facing a 16-in. computer screen. Eight loudspeakers (JBL control 1 Pro) were placed in a semicircular arrangement around the participant with an angular disparity of 25.7° between speakers and a distance of 93 cm from the participant (Fig. 1). The semicircular arrangement was preferred to a circular arrangement to avoid the increased difficulty of front–back discriminations. The heights of the loudspeakers varied as documented in Fig. 1's caption to enhance discriminability. Each trial consisted of a prime and a probe display. Each display began with the presentation of a picture depicting the target instrument, followed by two simultaneously presented sounds from different locations. Participants were instructed to locate the target sound by manually pressing one of four horizontally aligned keys on a response box while ignoring the distractor sound. For the ease of reference, speaker positions in Fig. 1 are labeled as L1–L8 from left to right; the keys of the response box are labeled accordingly with A–D. Pairs of speakers were mapped onto one response key. The assignment of the speaker pairs to the response keys was kept spatially compatible; that is, responses to the speaker pairs L1–L2, L3–L4, L5–L6, and L7–L8 required presses of the keys A, B, C, and D, respectively. Participants used their right and left middle and index fingers to operate the response keys.

Trials belonged to either the ignored repetition subdesign or the attended repetition subdesign. In the ignored repetition subdesign, feature repetitions between the prime distractor and the probe target were systematically manipulated, whereas in the attended repetition subdesign, feature repetitions between the prime target and probe target were varied. The ignored repetition subdesign was of primary theoretical interest. The attended repetition subdesign was primarily included to avoid predictability of the probe response based on prime responding, but the results obtained in this subdesign were also informative with

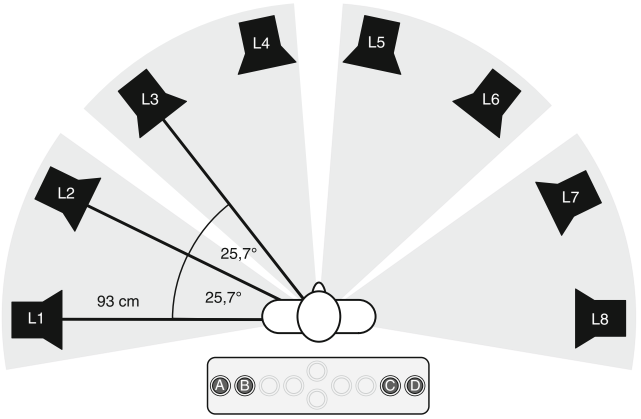

Fig. 1 Loudspeaker arrangement (labeled L1 to L8). Two loudspeakers were associated with the same response key (L1–L2 with key A, L3–L4 with key B, L5–L6 with key C, and L7–L8 with key D). Speaker heights were 102 cm for L3 and L8, 111 cm for L1 and L6, 129 cm for L4 and L7, and 138 cm for speakers L2 and L5

respect to the general mechanisms underlying auditory selection.

First, trials in the ignored repetition subdesign were constructed by generating a set of so-called *basic* prime–probe trials. Basic trials did not include any response or location repetitions between the four stimuli on the trial. This implies that all four prime and probe stimuli of a basic trial had to be associated with different response categories. Given four possible response categories (i.e., the response keys A–D), there were 24 prime–probe response combinations, resulting in 24 basic trials. Because two speaker locations were mapped onto the same response key, actual stimulus locations for each of the 24 basic trials were determined by randomly selecting one of the two locations for each response category. All other trial types of the ignored repetition subdesign were constructed from this set of basic trials. Ignored repetition trials were created by presenting the prime distractor on each basic trial at the location of the probe target. For response control trials, the prime distractor was presented at the location that was adjacent to the probe target location and associated with the same response. Finally, a control trial was created by presenting the prime distractor at the location that was adjacent to the probe target location but was linked to a different response key. Note that the basic trials and the control trials were similar in that they both lacked location and response repetitions. The crucial difference between these two trial types is that for all control trials, but not for the basic trials, the probe target was presented at the location adjacent to the prime distractor. In this respect, control trials were parallel to response control trials, both of them having the same physical distance between prime distractor and probe target location, differing only with regard to the prime distractor-to-probe target response repetition. As an exception, response control and control trials did not exhibit the same physical distance (25.7°) between prime distractor and probe target location when the probe target was presented at L1 or L8. For probe targets presented at L1, the prime distractor of the appropriate response control trial was presented at L2, whereas it was presented at L8 on the respective control trial. Given the semicircular (instead of a full circular) arrangement of the loudspeakers, this implied a larger location distance in the latter trial type, which might influence responding. As a consequence, all quadruples (basic, control, response control, ignored repetition) with the probe target at L1 or L8 were excluded from the statistical analysis.

In the process of constructing quadruples of parallel trials (basic, control, response control, ignored repetition), invalid control trials were occasionally generated (e.g., trials that contained response repetitions between prime distractor and probe distractor). In these cases, the whole quadruple of trials was discarded and generated anew. The algorithm was repeated until 96 unique trials (24 of each trial type) were generated.

Next, sound identity information was added to the trials. Each of the 96 trials was once implemented without any sound identity repetition between prime and probe presentation and once with a sound identity repetition between prime distractor and probe target. The former trials require the presentation of four different stimulus identities as target and distractor sounds. In each case, sound identities were selected individually for each trial. Adding sound identity to the four trial types resulted in a total of eight different trial types in the ignored repetition design. In fact, basic trials were presented in the experiment but not included in the analysis, given that there were designated control trials with preferable properties. Figure 2 provides examples of the six theoretically most relevant trial types in the ignored repetition design.

The same algorithm as that described above was applied to construct trials in the attended repetition subdesign, except that all repetitions (*location*, *response*, *identity*) referred to the targets in prime and probe, resulting in 192 trials in this subdesign. Overall, the experimental set containing 384 trials was presented in random order.

Procedure

Two training phases were administered to ensure that participants were able to discriminate between locations (training 1) and to familiarize them with the assignment of locations to response keys (training 2). Throughout the training, the target sound was indicated by a picture of the to-be-heard instrument on the computer screen. In training 1, participants saw a schematic image of the semicircular speaker arrangement on the screen. The task was to locate a target sound in the presence of a simultaneous distractor by performing a mouse click on the appropriate speaker in the image. Targets comprised all possible combinations of sounds and locations. Distractors were randomly chosen, with the restriction that they matched neither the location nor the sound identity of the target. Training 2 began after 75 % of the past 15 trials had received correct responses. In training 2, participants had to localize target sounds in the presence of distractors by pressing the respective keys of the response box as in the experiment proper. Randomly drawn prime trials of the experimental set were presented as stimuli. Participants proceeded to the experimental trials after at least 75 % of the past 15 trials had received correct responses.

Experimental trials began with the presentation of a cue depicting the to-be-attended instrument. The prime sounds were presented 500 ms after the onset of the visual cue. The picture remained visible until a response was made or an interval of 3,000 ms was exceeded. After the response, a 1,000-ms prime–probe interval elapsed before the onset of the visual probe cue, followed by the probe sounds after another 500 ms. All responses faster than 100 ms and slower than 3,000 ms were counted as invalid. Audio-visual feedback

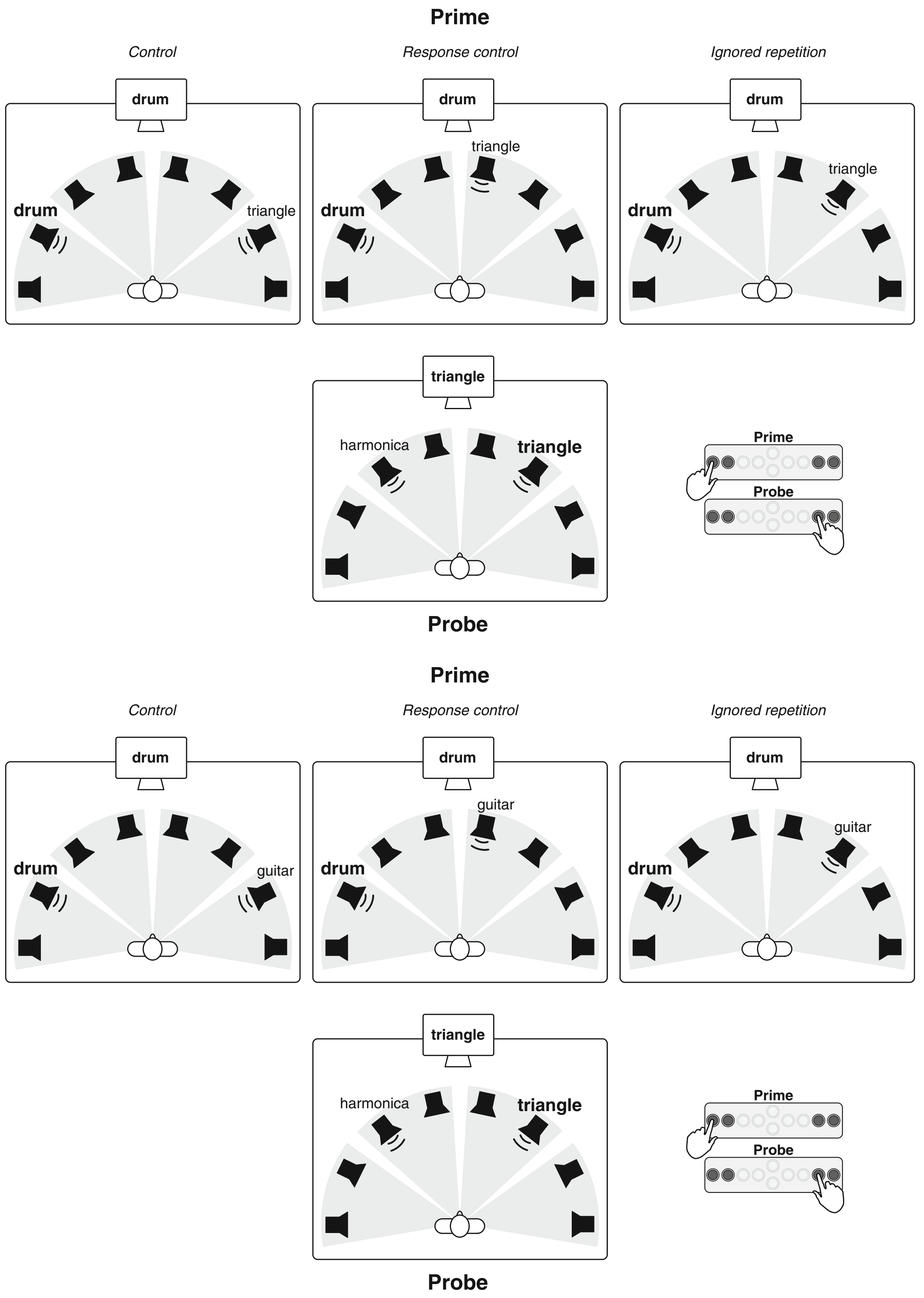

Fig. 2 Illustrative examples of the three crucial prime–probe trial types (control, response control, ignored repetition) in the ignored repetition subdesign. The upper panel illustrates trials with a prime distractor to probe target sound repetition; the lower panel shows trials with a prime distractor to probe target sound change. The key layout and the correct prime and probe responses for the examples are displayed for both panels. The target sound was visually cued on the monitor in front of the participant. To simplify matters, the visual cue is depicted as a written word, and not in picture format (here,“drum” in the prime, “triangle” in the probe)

of the correctness of both responses was displayed for 1,000 ms after the probe response had been executed. A 1,000-ms intertrial interval preceded the next trial. After every 12th trial, participants received feedback summarizing their response speed and accuracy in the current block. They initiated the next block at their own discretion. The experiment lasted about 74 min.

Design

The experiment comprised two subdesigns (ignored repetition, attended repetition), but the ignored repetition subdesign was of primary interest. The 3 × 2 ignored repetition subdesign comprised a repeated measures design with *trial type* (control, response control, ignored repetition) and *sound repetition* (repeated vs. changed) as within-subjects variables. The primary dependent variable was participants' average reaction time, but error rates were also analyzed.

Hypothesis testing was based on the two planned contrasts (1) between response control and control trials and (2) between ignored repetition and response control trials. The former comparison tested the sole impact of executing the prior distractor response, while the latter isolated the effect of responding to a location that was occupied by the distractor in the previous presentation. In addition, ignored repetition trials were compared with control trials to assess the standard spatial negative priming effect. However, the result of this comparison is not diagnostic with respect to the underlying mechanisms and is, therefore, not treated as theoretically relevant. An a priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) showed that given $\alpha = \beta = .05$, a sample size of $N = 70$ was necessary to detect effects of size $d_z = 0.40$ (medium to small effects in terms of Cohen, 1988) between response control and control trials, as well as between ignored repetition and response control trials. We were able to collect data from $N = 80$ participants, so that the power was somewhat larger than what we had planned for $(1 - \beta = .97)$. The global level of alpha was maintained at .05. The Bonferroni–Holm method (Holm, 1979) was applied to prevent α-error accumulation for the two planned contrasts. All reported *t*-tests for the planned contrasts were one-tailed, while comparisons that were not directly related to the hypotheses were based on two-tailed *t*-tests. Because no directed hypotheses were formulated for the attended repetition subdesign, all reported *t*-tests for this subdesign are two-tailed.

Results

Response accuracy for both training phases was high, with 81 % (*SD* = 1.06) and 89 % (*SD* = 1.91) mean correct responses for the last 15 trials in training 1 and 2, respectively. One-sample *t*-tests confirmed that performance was above chance (i.e., above 12.5 % and 25 % correct responses for training 1 and 2, respectively), with $t(79) = 87.49$, $p < .001$, $d_z = 9.78$ for training 1 and $t(79) = 71.43$, $p < .001$, $d_z = 7.99$ for training 2. Thus, participants were able to discriminate between adjacent locations well, and they also mastered the location–response mapping of the experimental task proper.

Attended repetition trials were primarily employed to obscure global contingencies between prime and probe presentations but were also included in the statistical analysis because they are also informative with respect to the general mechanisms underlying auditory selection. Results for both subdesigns are shown in Table 1. Only probe responses following correct prime responses were used to evaluate response speed and accuracy. Separate analyses were conducted for sound-repeated and sound-changed trials to separate effects of location–identity mismatch. Following the Bonferroni–Holm rationale (Holm, 1979), *p*-values for the (in the present case, two) hypothesis-relevant comparisons were arranged in ascending order, starting with the smallest value. Dividing the global alpha level of .05 by the number of comparisons adjusted the critical alpha level for the decision about the smallest *p*-value to .025, while the critical alpha level for the second comparison remained at .05. For convenience, the critical alpha levels are now reported in brackets after the exact empirical *p*-values. The statistical analysis is reported for the ignored repetition subdesign, followed by the attended repetition subdesign.

For sound-changed trials, presenting the probe target stimulus at the former location of the prime distractor on the ignored repetition trials prolonged response times, relative to control trials, $t(79) = 2.61$, $p = .012$, $d_z = 0.29$. The standard spatial negative priming effect was thus present in the data. However, it could have been caused by response or location inhibition, as well as feature mismatching. Executing the response that had been successfully withheld in the preceding prime (i.e., response control trials) was not significantly slowed down, as compared with control trial responses, $t(79) = 0.61$, $p = .272$ $[\alpha{=}.050]$, $d_z = 0.07$. Furthermore, responses were slower on ignored repetition than on response control trials, $t(79) = 2.04$, $p = .023$ $[\alpha = .025]$, $d_z = 0.23$.

Among sound-repeated trials, there was a descriptive trend showing faster responses on ignored repetition than on control trials, $t(79) = -1.66$, $p = .102$, $d_z = 0.19$. Again, disentangling the causal mechanisms for this result demanded two comparisons. Examination of response control trials revealed no statistically significant effect of executing the prior distractor response, relative to control trials, $t(79) = 0.82$, $p = .207$ $[\alpha = .050]$, $d_z = 0.09$. Response speed was significantly faster on ignored repetition than on response control trials, $t(79) = -2.17$, $p = .017$ $[\alpha = .025]$, $d_z = 0.24$.

The analysis of error rates did not compromise the response time results, because no statistically significant differences were obtained in any of the relevant comparisons.

Table 1 Mean response times (RTs, in milliseconds) and error rates for all trial types in the ignored repetition subdesign (above) and the attended repetition subdesign (below); mean effects are shown in the lower part of each subdesign (with standard deviations in parentheses)

	Ignored repetition subdesign			
	Sound changed		Sound repeated	
Trial type	RT	Error rate	RT	Error rate
Control (C)	912 (220)	.137 (.097)	916 (216)	.125 (.102)
Response control (RC)	921 (223)	.147 (.100)	926 (216)	.117 (.115)
Ignored repetition (IR)	945 (238)	.142 (.096)	896 (219)	.132 (.099)
Basic	897 (202)	.114 (.078)	905 (211)	.117 (.097)
Negative priming effect (IR − C)	*33* (*112*)	*.005* (*.099*)	*−20* (*106*)	*.007* (*.105*)
Response effect (RC − C)	*9* (*130*)	*.010* (*.093*)	*10* (*111*)	*−.008* (*.119*)
Location effect (IR − RC)	*24* (*105*)	*−.005* (*.102*)	*−30* (*123*)	*.015* (*.114*)

	Attended repetition subdesign			
	Sound changed		Sound repeated	
Trial Type	RT	Error rate	RT	Error rate
Control (C)	859 (208)	.093 (.090)	806 (170)	.107 (.085)
Response control (RC)	916 (209)	.211 (.139)	816 (188)	.140 (.109)
Attended repetition (AR)	893 (214)	.156 (.137)	682 (156)	.033 (.051)
Basic	864 (209)	.091 (.088)	824 (188)	.102 (.088)
Repetition Priming effect (AR - C)	*34* (*102*)	*.063* (*.134*)	*-124* (*100*)	*-.074* (*.085*)
Response effect (RC - C)	*57* (*118*)	*.118* (*.140*)	*10* (*103*)	*.033* (*.110*)
Location effect (AR - RC)	*-23* (*103*)	*-.055* (*.143*)	*-134* (*91*)	*-.107* (*.101*)

Note. In the ignored repetition subdesign, feature repetitions in all trial types occur between prime distractor and probe target stimuli, whereas they occur between prime and probe target stimuli in the attended repetition subdesign.

Specifically, for sound-changed trials, ignored repetition and response control trials did not differ from control trials, with $t(79) = 0.47$, $p = .320$, $d_z = 0.05$, and $t(79) = 0.99$, $p = .161$ [$\alpha = .025$], $d_z = 0.11$, respectively. Error rates on ignored repetition trials were comparable to those on response control trials, $t(79) = -0.45$, $p = .327$ [$\alpha = .050$], $d_z = 0.05$. With sound-repeated trials, error rates differed neither between ignored repetition and control trials, $t(79) = 0.55$, $p = .293$, $d_z = 0.06$, nor between response control and control trials, $t(79) = -0.60$, $p = .275$ [$\alpha = .050$], $d_z = 0.07$. Finally, no difference was obtained between ignored repetition and response control trials, $t(79) = 1.13$, $p = .131$ [$\alpha = .025$], $d_z = 0.13$. Mean response times and error rates for the hypothesis-relevant trial types in the ignored repetition subdesign are shown in Fig. 3.

Keep in mind that for trials in the attended repetition subdesign, prime target to probe target repetitions define the different trial types: On attended repetition trials, the target location and response repeated from prime to probe, whereas on response control trials, only the correct response was repeated. There was no location or response repetition on control trials. All trial types could be implemented with a sound identity change between prime and probe target (sound-changed trials) or with a sound identity repetition (sound-repeated trials). The same testing rationale was used as in the ignored repetition subdesign.

Among sound-changed trials, repeating the target location between subsequent presentations in attended repetition trials, as well as solely reexecuting the response between prime and probe on response control trials, yielded longer response times than on control trials, $t(79) = 2.94$, $p = .004$, $d_z = 0.33$, and $t(79) = 4.30$, $p < .001$ [$\alpha = .025$] , $d_z = 0.48$, respectively. Responding on attended repetition trials was faster, as compared with response control trials, $t(79) = -2.02$, $p = .047$ [$\alpha = .050$], $d_z = 0.23$.

For sound-repeated trials, the analysis revealed that responding in attended repetition trials was facilitated, relative to response control and control trials, $t(79) = -13.21$, $p < .001$ [$\alpha = .025$], $d_z = 1.48$, and $t(79) = -11.00$, $p < .001$, $d_z = 1.23$, respectively. Response control and control trials did not differ, $t(79) = 0.88$, $p = .380$ [$\alpha = .050$], $d_z = 0.10$.

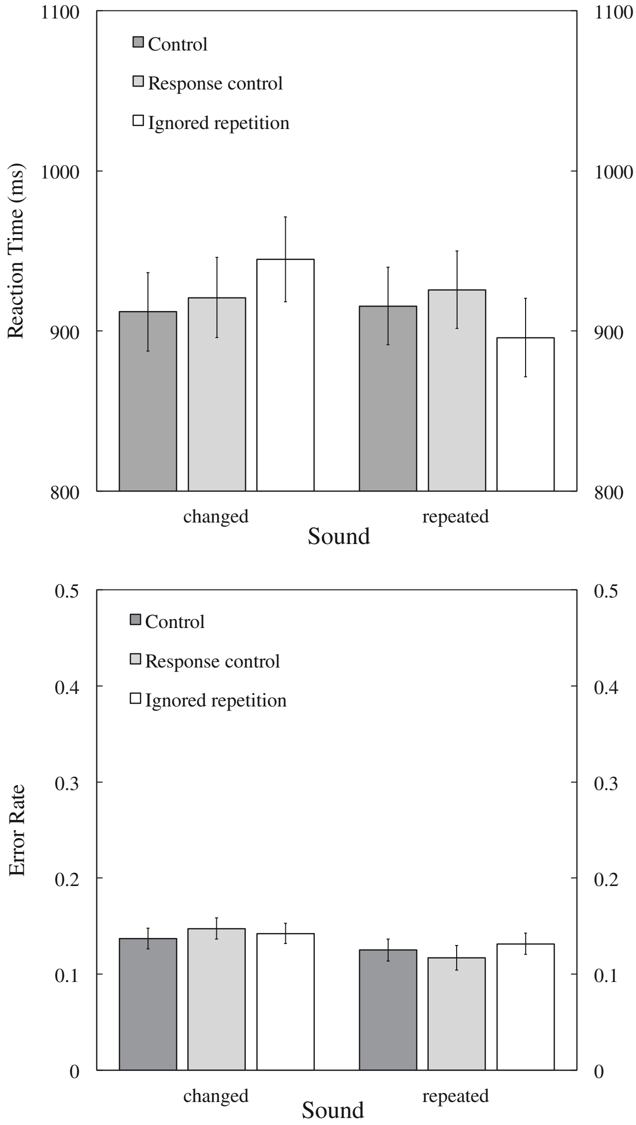

Fig. 3 Mean reaction times (upper panel) and error rates (lower panel) as a function of trial type (control, response control, ignored repetition) and sound repetition (repeated vs. changed) for the ignored repetition subdesign. The error bars depict the standard errors of the means. Note that the standard errors cannot be used to estimate any differences between the displayed conditions

The analyses of the error rates led to the same pattern of statistical inferences as the reaction time data, with the only difference that accuracy was reliably lower on response control trials with sound identity repetition than on the respective control trials, $t(79) = 2.68$, $p = .009$ [$\alpha = .050$], $d_z = 0.30$.

Discussion

The present study was designed primarily to test whether distractor-related response inhibition operates in auditory selective attention as measured in the spatial negative priming task. For trials with a sound change between prime distractor and probe target, responding to an object at a previously ignored location was prolonged, as compared with other locations. This is the standard spatial negative priming effect, which can be explained by a number of different theoretical accounts (Buckolz et al., 2004; Neill & Valdes, 1992; Park & Kanwisher, 1994; Tipper et al., 1990). Comparing response control with control trials revealed that the need to execute a prior distractor response did not affect response latency. This result contradicts the prediction derived from the response inhibition account that has been put forward to explain visual spatial negative priming (Buckolz et al., 2004; Guy & Buckolz, 2007; Guy et al., 2006).

The fact that, on sound-changed trials, responses were slower on ignored repetition than on response control trials can still be explained by the location inhibition (Milliken et al., 1994; Tipper et al., 1990), the episodic retrieval account (Neill & Valdes, 1992; Neill et al., 1992), and feature mismatching account of spatial negative priming (Park & Kanwisher, 1994). The location inhibition and the episodic retrieval accounts predict impaired performance on ignored repetition trials, relative to response control trials, irrespective of whether there is a feature match or a mismatch at the repeated location between prime and probe. In contrast, the feature mismatching account implies performance on ignored repetition trials with a feature match to be equivalent to, or even better than, that on response control trials. The latter is what was found here (note that the descriptive results were parallel for the difference between ignored repetition and control trials). This result is uniquely predicted by the feature mismatching account of spatial negative priming and cannot be explained by location-based inhibition or episodic retrieval. If anything, the retrieval of inappropriate prime information should be even stronger when identical stimulus–location configurations are repeated between prime and probe displays, constituting a more efficient retrieval cue than just a repeated location. Furthermore, comparisons among sound-repeated trials revealed equivalent response times for response control and control trials, which is additional evidence against the response inhibition account of spatial negative priming.

The results are compatible with the feature mismatching account proposed by Park and Kanwisher (1994). The conclusion that feature mismatching explains spatial negative priming is also supported by other empirical studies of auditory spatial negative priming (Mayr et al., 2011; Mayr et al., 2009). At a more abstract level, these results underscore the utility of the concept of object files in auditory selective attention, and they nicely fit with the growing empirical basis of object-binding phenomena in a variety of experimental paradigms in audition (Dyson & Ishfaq, 2008; Hall, Pastore, Acker, & Huang, 2000; Maybery et al., 2009; Mondor, Zatorre, & Terrio, 1998; Parmentier, Maybery, & Elsley, 2010; Zmigrod & Hommel, 2009, 2010).

The absence of response-related aftereffects in auditory spatial negative priming differs from related findings in the visual modality (Buckolz et al., 2004; Guy & Buckolz, 2007; Guy et al., 2006) and might, therefore, be informative with respect to modality-specific mechanisms underlying target selection in the presence of distractor information. The need to execute a previously distractor-assigned response did not slow down responding. This may indicate that, in auditory selection, (1) initial activation of responses to distractors is absent (or substantially reduced), (2) distractor-related response activation is not inhibited, or (3) activation of irrelevant motor responses is indeed counteracted by an inhibitory process but produces no measurable aftereffect on responding on the subsequent trial.

With respect to the first point, the response inhibition account proposed by Buckolz et al. (2004) assumes that the activation of distractor-assigned responses is followed by inhibition, impairing the subsequent response execution. Specifically, the activation of distractor-assigned responses is a prerequisite for their subsequent inhibition. Reduced motor activation by spatially presented distractor sounds might be the consequence of a lower degree in compatibility between auditory stimuli and manual responses—as compared with the compatibility between visual stimuli and manual responses—which has been proposed for spatial tasks (Wickens, Sandry, & Vidulich, 1983; Wickens, Vidulich, & Sandry-Garza, 1984). If a distractor response was not (sufficiently) activated, it might not call for an engagement of an inhibitory process to prevent false responding. Although the absence of response activation for auditory distractor information may, in principle, account for the present finding, we think that this is not likely. Evidence from tasks presenting so-called *accessory* stimuli suggests that manual responses can be activated by irrelevant auditory objects, differing from the target object in identity and location. In these tasks, left and right responses are arbitrarily assigned to a nonspatial feature (e.g., color or shape) of a centrally presented visual stimulus. The visual imperative stimulus is simultaneously accompanied by an auditory accessory stimulus. This arrangement is used to evaluate the influence of spatial features of an irrelevant auditory stimulus by manipulating the relation between its spatial location and the location of the appropriate response to the imperative visual stimulus. Responding to the imperative stimulus is systematically influenced by the spatial location of the auditory accessory stimulus, yielding a *Simon-like* pattern of better performance if the accessory stimulus is presented at the same side as the required response, as compared with the other side (Nishimura & Yokosawa, 2009; Notebaert & Soetens, 2003, Experiment 2; Proctor, Pick, Vu, & Anderson, 2005). This pattern of results is commonly explained in terms of the dimensional overlap model (Kornblum, Hasbroucq, & Osman, 1990), assuming that the accessory stimulus automatically activates the spatially corresponding response. If the activated response conforms to the required response, response latency and accuracy are improved, while conflicting responses impair performance. Response activation seems to occur even though the stimulus is completely irrelevant to the task. This demonstrates that a task-irrelevant auditory stimulus, differing in location, identity, and even modality from the target, might nevertheless activate a spatially corresponding response. Considering this evidence, response activation by the irrelevant distractor in the spatial negative priming task seems likely.[3] As a result, the absence of motor-related inhibitory aftereffects in the task used here was most likely not due to insufficient response activation in the prime, giving rise to the possibilities that distracting motor responses are generally not inhibited or an inhibitory mechanism suppresses distractor-assigned responses but causes no impairment of their subsequent use. Note that the impact of (mis-)matching stimulus features on responding demonstrates that aftereffects could, in principle, be detected in our task. The absence of evidence for motor response inhibition while, at the same time, feature (mis-)match effects could be found might indicate different time courses of these aftereffects. Whereas memory for identity–location features survived the present prime–probe interval of 1,000 ms, aftereffects of response inhibition might be a more transient phenomenon that is too short-lived to impair future performance. This would imply that response inhibition takes place but is presumably of no major consequence for subsequent responding. Although the present experiment cannot readily be used to ultimately decide whether inhibition is transient or absent in auditory selection, we argue in favor of the latter alternative. This argumentation is primarily based on a recent auditory spatial negative priming study—comparable to the one by Mayr et al. (2011)—in which we manipulated

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[3] There are several differences between the accessory and the spatial negative priming task. The spatial negative priming task presents auditory targets simultaneously with auditory distractors, while in the accessory task a single distractor sound accompanies a visual target stimulus. In addition, spatial location is a relevant stimulus feature in the spatial negative priming task, while it is completely irrelevant in the Simon-like accessory task. However, these differences might even argue for a stronger degree of response activation associated with distractor stimuli in the spatial negative priming task than in the accessory task. This should be so because an even stronger response activation by irrelevant stimuli might emerge when location becomes a response-relevant dimension and when target and distractor stimuli cannot be distinguished easily by their modality.

the response–stimulus interval (RSI) between prime response and probe target sounds, with RSIs of 100, 750, or 1,400 ms. We reasoned that, if response inhibition is indeed present but transient, it should selectively affect probe responding after short RSIs. However, we found that responding was equivalent for all RSI levels, and the response behavior was exclusively determined by feature mismatches, which further supports the idea that auditory selection is not achieved by inhibitory processes. In sum, our data can be taken as evidence that inhibition does not affect distractor-related motor responses, at least not in a way that slows the subsequent reuse of these responses.

On the basis of findings in the visual modality, the spatial negative priming effect has been explained in terms of an *inhibition of return* (IOR) mechanism (for reviews, see Klein, 2000; Taylor & Klein, 1998). In essence, the IOR explanation of the spatial negative priming effect assumes that spatial attention is directed to target, as well as distractor stimuli, during the prime presentation, followed by an inhibitory process that prevents the subsequent reorientation of attention, leading to impaired stimulus processing at all previously occupied locations in the probe. In accordance with this explanation, Christie and Klein (2001) and Milliken et al. (2000) found impaired performance in a visuospatial negative priming task when the probe target was presented at a location that contained target or distractor stimuli during the prime (see Christie & Klein, 2008, for the crucial role of target repetition trials in testing theories of spatial negative priming). However, such an IOR-consistent pattern of results has not always been found for attended repetition trials in visuospatial priming tasks (see Guy et al., 2006).

Turning to the present auditory priming task, note that the pattern of results in the ignored repetition subdesign was not compatible with an IOR account of auditory spatial negative priming, because there was no general decline in performance when the probe target appeared at the previously ignored location. Instead, performance declined when a feature mismatch was present at that location. Thus, it appears that IOR was not involved, or at least did not determine performance, on the ignored repetition trials of the present task.

At odds with an IOR explanation and different from findings in the visual modality (Christie & Klein, 2001; Milliken et al., 2000), presenting the probe target at the location of the former prime target did not generally impair responding in the present auditory task. In fact, a full repetition of sound, location, and response features between successive target stimuli had a strong facilitative effect on performance, as compared with the respective control condition. All other conditions in the attended repetition subdesign that contained only partial repetitions—that is, response control trials with a sound and response repetition but a location change, response control trials with a response repetition but a sound and location change, and attended repetition trials with a location and response repetition but a sound change—resulted in impaired performance, relative to their respective control trials.

Milliken et al. (2000) argued that IOR effects might be (sometimes) counteracted by facilitative repetition effects of nonspatial stimulus features (such as color in the visual modality or, in the present auditory task, sound identity and also response features). However, a facilitative nonspatial feature repetition effect overcompensating for a slowdown due to IOR cannot account for the present facilitative effect on full repetition trials, since the corresponding control trials also comprised sound, as well as response repetitions, between successive targets. Therefore, neither the findings of the ignored repetition subdesign nor the results of the attended repetition subdesign are compatible with the IOR account that predicts impaired responding to all previously occupied locations.

The results from the attended repetition subdesign are also incompatible with the assumption that feature dimensions are processed independently. If this were true, response facilitation in attended repetition trials should have gradually increased with the number of repeated features. Instead, the overall pattern of results is most parsimoniously explained by assuming auditory event file binding, extending the concept of object files to include response information (Zmigrod & Hommel, 2009, 2010). Within this framework, presenting individual features of the prior episode retrieves all features of the respective event file, leading to impaired performance whenever the retrieved information does not meet the perceptual or response-related requirements of the current situation. This is the case in partial repetitions. In contrast, responding is assumed to be facilitated if stimuli fully match in all features from the prior episode. The prediction of impaired performance for partial and improved performance for full repetitions is, overall, supported by the results of the attended repetition design and, therefore, stresses the impact of binding processes in the auditory domain and the explanation of the results in the ignored repetition design in terms of the feature mismatching hypothesis (Park & Kanwisher, 1994).

Beyond showing that auditory spatial negative priming can be explained exclusively by feature mismatching (and not by response inhibition, location inhibition, or episodic retrieval), the present results contribute to the understanding of processes underlying spatial selective attention in audition in general. First, inhibition of distractor-related motor responses does not seem to be a relevant mechanism of auditory selective attention. Second, further evidence of the formation of auditory object files was found, supporting object binding as a general coding principle even for to-be-ignored distractor events (Mayr et al., 2011; Mayr et al., 2009; Zmigrod & Hommel, 2009, 2010). Nevertheless, the conditions under which feature mismatches affect behavior are still under investigation. As for identity-based negative priming tasks—in which responding is determined by the stimulus identity of a sound—location–identity mismatch effects are usually not found (e.g., Banks et al., 1995; Buchner & Mayr, 2004; Buchner & Steffens, 2001; Mondor, Leboe, & Leboe, 2005). This means that the slowdown in responding to a previously ignored sound identity does not depend on whether the repeated sound is presented at the same or another location (e.g., ear) in the prime and probe. However, it is possible that the absence of feature mismatch effects in auditory identity negative priming is due to the minor relevance of location information in these tasks. In favor of this idea, location–identity mismatch effects are found in identity negative priming tasks when spatial aspects of the stimulus presentation are made more available during sound processing. For example, in the study of Mayr et al. (2011; see also Leboe, Mondor, & Leboe, 2006), participants identified a target sound in the presence of a simultaneous distractor presented from another of four spatially separated loudspeakers. By using speakers instead of headphones, binaural localization cues were available in a presumably more naturalistic format to aid the processing of spatial sound features. The authors argued that, if the processing of spatial sound characteristics is possible, effects of identity–location mismatches emerge, whereas they might not appear otherwise. In conclusion, feature mismatches seem to be an important but not mandatory characteristic of auditory processing and might be influenced by the significance of spatial attributes in the task at hand.

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The time-course of distractor processing in auditory spatial negative priming

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Abstract

The spatial negative priming effect denotes slowed-down and sometimes more error-prone responding to a location that previously contained a distractor as compared with a previously unoccupied location. In vision, this effect has been attributed to the inhibition of irrelevant locations, and recently, of their task-assigned responses. Interestingly, auditory versions of the task did not yield evidence for inhibitory processing of task-irrelevant events which might suggest modality-specific distractor processing in vision and audition. Alternatively, the inhibitory processes may differ in how they develop over time. If this were the case, the absence of inhibitory after-effects might be due to an inappropriate timing of successive presentations in previous auditory spatial negative priming tasks. Specifically, the distractor may not yet have been inhibited or inhibition may already have dissipated at the time performance is assessed. The present study was conducted to test these alternatives. Participants indicated the location of a target sound in the presence of a concurrent distractor sound. Performance was assessed between two successive *prime-probe* presentations. The time between the prime response and the probe sounds (response-stimulus interval, RSI) was systematically varied between three groups (600 ms, 1,250 ms, 1,900 ms). For all RSI groups, the results showed no evidence for inhibitory distractor processing but conformed to the predictions of the feature mismatching hypothesis. The results support the assumption that auditory distractor processing does not recruit an inhibitory mechanism but involves the integration of spatial and sound identity features into common representations.

Keywords: auditory, distractor processing, attention, inhibition, object-binding

Introduction

Humans usually interact efficiently with their environment. This is remarkable because, at any given moment, the cognitive system receives a multitude of sensory input that could potentially lead to action. As a consequence, successful processing of currently relevant information as well as preventing irrelevant information from influencing performance is essential for goal-directed behavior. While early research regarded the maintenance and amplification of currently relevant information as a prominent mechanism (e.g., Broadbent, 1970; Van der Heijden, 1981), evidence from different lines of research indicate that processes operating on non-target information also contribute to task-appropriate performance (for a review, see Houghton & Tipper, 1994). A widely used paradigm to investigate the mechanisms underlying goal-directed behavior is the spatial variant of the negative priming task (e.g., Tipper, Brehaut, & Driver, 1990). In this task, participants typically indicate the location of a target (specified by a non-spatial feature such as color or shape) in the presence of a simultaneously presented distractor at another location. Performance is assessed for successive presentations of target-distractor pairs, a *prime* pair followed by a *probe* pair. In so-called *ignored repetition* trials, the probe target is presented at the location that contained the distractor in the preceding prime, while no location repetition occurs between successive presentations in *control* trials. Slowed-down and sometimes more error-prone responding in ignored repetition as compared with control trials denotes the spatial negative priming effect. This effect has been frequently studied in the visual modality (e.g., Chao, 2009; Fitzgeorge & Buckolz, 2008; Milliken, Tipper, & Weaver, 1994; Tipper et al., 1990; Tipper, Weaver, & Milliken, 1995) and several theoretical accounts have been put forward to explain it. The traditional distractor inhibition account posits that the spatial representation of a distractor event is suppressed to facilitate target processing during the prime. Due to residual inhibition of that location responding to the probe target at the location is delayed (Milliken, Tipper, Houghton, & Lupiáñez, 2000; Tipper et al., 1990).

Retaining the notion that an inhibitory mechanism operates on distractor events, recent empirical findings have been interpreted in terms of a response-related origin of the visuospatial negative priming effect. The response inhibition account (Buckolz, Goldfarb, & Khan, 2004) postulates that distractor-assigned motor responses instead of spatial representations are suppressed to prevent false responding. The response activation triggered by the location of the distractor stimulus is counteracted by an inhibitory mechanism that actively suppresses the non-target response. Because the probe target location in ignored repetition trials requires the execution of the former prime distractor response, the visuospatial negative priming effect is assumed to be caused by the time-consuming need to overcome the inhibitory status of the currently required response.

There is compelling evidence for a response inhibition account of visuospatial negative priming (e.g., Buckolz et al., 2004; Guy & Buckolz, 2007; Guy, Buckolz, & Khan, 2006). In these studies, multiple stimulus locations were assigned to a common response to disentangle the effect of location and response repetition between prime distractor and probe target on performance. In line with the response inhibition account, probe responding was impaired when the probe target required the execution of a response that was previously withheld to the prime distractor location. Moreover, location repetition did not contribute to this effect: Responding was equally impaired when the probe target was presented at the location of the former prime distractor or at another location. This finding cannot be explained by the location-based inhibition account (Milliken et al., 2000; Tipper et al., 1990) and has led to the conclusion that distractor-assigned responses and not the distractors' spatial representations are inhibited as part of visual distractor processing. However, using the same rationale of mapping multiple locations to a common response key, Neill, Valdes, and Terry

(1995) actually reported evidence for location-based inhibition. In essence, their results showed that responding to the probe target location was additionally impaired when the specific location contained the distractor in the preceding prime as compared with trials in which prime distractor and probe target were presented at different locations which were, however, assigned to the same response key. In sum, while it may still be unclear whether spatial or response-related features of distractor events (or both) are suppressed, it is largely agreed that the visuospatial negative priming effect indicates the operation of an inhibitory mechanism (for a review, see Tipper, 2001).

Recently, the spatial negative priming paradigm has been used to investigate distractor processing in the auditory modality. In a study of Mayr, Buchner, Möller, and Hauke (2011), two (out of four) instrumental sounds were presented from two (out of four) speakers, placed in a semi-circular arrangement around the participant. The task was to locate a visually-precued instrumental sound in the presence of a simultaneous distractor sound presented from a different speaker. Each speaker was assigned to a distinct response. In ignored repetition trials, the probe target sound was presented from the speaker that had emitted the distractor sound during the prime. In addition, sound identity was orthogonally manipulated so that prime distractor and probe target either comprised the same sound or different sounds. Trials devoid of sound identity and location repetition between successive presentations served as control. In contrast to the typical finding in the visual modality, presenting the probe target at the location of the former prime distractor—and thus demanding the execution of a previously withheld response—did not generally prolong responding relative to control trials. Instead, performance in ignored repetition trials was only delayed when prime distractor and probe target mismatched in sound identity; performance did not differ from control trials when both events comprised the same sound. This pattern of results cannot be explained by an inhibitory mechanism that suppresses spatial representations or responses of distractor events (for a parallel data pattern, see Mayr, Hauke, & Buchner, 2009; Mayr, Möller, & Buchner, 2014; Möller, Mayr, & Buchner, 2013). Thus, while there is strong evidence of distractor response inhibition in vision, all previous reports of auditory spatial negative priming did not find any evidence of inhibitory distractor processing. Instead, the pattern of results is well in line with the feature mismatching hypothesis of spatial negative priming (Park & Kanwisher, 1994).

According to the feature mismatching hypothesis (Park & Kanwisher, 1994), stimulus processing in prime and probe entails the integration of spatial and identity features of target as well as distractor events into common representations—so-called *object files*—which are stored in short-term memory (Kahneman, Treisman, & Gibbs, 1992; Treisman, 1993; Treisman & Gelade, 1980). To illustrate, presenting the sound of a guitar as the prime target from the front left speaker and the sound of a harmonica as the prime distractor from the front right speaker generates two object files that contain sound identity and spatial information about each event (i.e.“front left, guitar” and “front right, harmonica”, respectively). Further, it is assumed that the whole content of an object file is retrieved from memory when at least one of its features is encountered in a subsequent presentation. In ignored repetition trials, presenting the probe target sound (e.g. “snare drum”) from the front right speaker that emitted the distractor during the prime leads to the retrieval of the object file previously associated with that location. In the present example, the retrieved object file (“front right, harmonica”) does not fully correspond to the current stimulus presentation (“front right, snare drum)” and delays probe responding due to a time-consuming updating of the object file. In contrast, no updating process occurs when the retrieved object file fully conforms to the current stimulus and, consequentially, performance is not affected (see also, Zmigrod & Hommel, 2009; Zmigrod & Hommel, 2010). In line with the object file framework, Mayr et al. (2011) reported impaired performance when the prime distractor and probe target appeared at the same location but differed in identity and also when prime distractor and probe target comprised the same sound identity but were presented from different speakers. The latter case also denotes a case of feature mismatch in which object file retrieval is triggered by the sound repetition between prime distractor and probe target but the spatial information for that sound has to be updated in the respective object file[1].

In sum, studies on visuospatial negative priming suggest that goal-directed behavior is achieved by the suppression of distractor-assigned responses (e.g., Buckolz et al., 2004; Fitzgeorge, Buckolz, & Khan, 2011; Guy et al., 2006), their locations (e.g., Milliken et al., 1994; Neill et al., 1995; Tipper et al., 1990), or both. In contrast, all previous studies of auditory versions of the task revealed no evidence for inhibitory distractor processing, but supported the feature mismatching hypothesis (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014; Möller et al., 2013). Together, this might be taken as evidence that the mechanisms that prevent responding to non-target events in vision differ from those operating in audition.

However, this would be premature because the absence of evidence for inhibition in auditory spatial negative priming may have an alternative explanation that refers to the dynamics of inhibitory distractor processing. For instance, Buckolz, Avramidis, and Fitzgeorge (2008) examined the time-course of response-related inhibition in a visuospatial negative priming task. Most important for the present purpose, participants in the “distractor-

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[1] Note that this effect was found in most, but not in all auditory spatial negative priming tasks which might indicate that object file retrieval is more effectively triggered by location repetitions (as compared with sound identity repetitions) between prime distractor and probe target. Moreover, evidence for feature mismatching effects has also been reported in visuospatial negative priming (Park & Kanwisher, 1994). However, several studies found reliable spatial negative priming effects in the absence of feature mismatches (Milliken et al., 2000; Tipper et al., 1995), so that this mechanism seems to be only of minor importance in the visual modality

plus-target" group of Experiment 1 were presented with prime-probe sequences that each required a keypress response to the location of a green rectangle in the presence of a concurrent red distractor rectangle presented at two out of four horizontally-aligned screen locations. The response-stimulus interval (RSI) between the prime response and the subsequent probe display was set block-wise to 2, 5, or 10 seconds. The results revealed that the RSI manipulation affected the size of the spatial negative priming effect: The spatial negative priming effect which was found for all RSI levels was reliably larger when prime response and probe onset were separated by 2 seconds as compared with an RSI of 5 and 10 seconds which, in turn, produced effects of equal size. In their Experiment 2, prime presentations always comprised either a single target or distractor stimulus while target and distractor stimuli were simultaneously presented in the corresponding probe. Most important, the offset of the prime stimulus and the onset of the following probe stimuli was separated block-wise by either 75 ms or 750 ms. Performance was compared between ignored repetition and control trials and revealed a typical visuospatial negative priming effect in the 750 ms condition. Interestingly, performance in ignored repetition trials was facilitated as compared with control trials when prime and probe events were separated by 75 ms[2].

These results may be taken to indicate that, in visuospatial negative priming, response inhibition takes a few hundred milliseconds to develop and then peaks before it decays (see also Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991, Experiment 3).

Turning to spatial negative priming in audition, all previous studies of auditory spatial negative priming employed an RSI of 1,500 ms between the execution of the prime target response and the onset of the corresponding probe sounds (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014; Möller et al., 2013). Therefore, it could be argued that an inhibitory

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[2] Ignored repetition and control trials in Experiment 2 did not require a prime response.

mechanism also operates in auditory spatial negative priming, but no after-effect of that processing (i.e., no spatial negative priming effect) has yet been obtained due to the inappropriate timing of prime and probe events in prior studies. Given the proposed dynamics of inhibition, it might have been either the case (1) that inhibition had not yet been sufficiently applied to the prime distractor or (2) that inhibition had already dissipated at the time the probe target was presented at the former prime distractor location or required the previously withheld response. Because the prime distractor response or location was either *not yet* or *no longer* sufficiently suppressed, probe performance in ignored repetitions trials was not impaired as compared with control trials, so that no spatial negative priming effect in audition emerged.

Therefore, we decided to test these possibilities by conceptually replicating the auditory spatial negative priming experiment of Mayr et al. (2011) with three experimental groups that systematically differed with respect to the interval between the prime response and the onset of the probe sounds (henceforth response-stimulus interval or RSI). We chose these RSI values because they comprised intervals shorter (600 ms and 1,250 ms) and an interval longer (1,900 ms) than the 1,500 ms-RSI typically used in prior studies of auditory spatial negative priming. This allowed us to gain first insight into the specific time-course of auditory distractor processing and to assess whether any evidence for inhibitory processing was missed in prior studies.

In the present experiment half of the experimental trials included a prime distractor-to-probe target location repetition while the other half of the trials did not. Specifically, *sound-changed, location-changed* trials were devoid of any repetitions between successive presentations and served as control trials. The sound identity but not the sound location was repeated between prime distractor and probe target in *sound-repeated, location-changed* trials, whereas the spatial position but not the identity was repeated in *sound-changed,* *location-repeated* trials. Prime distractor and probe target were identical with respect to both features in *sound-repeated, location-repeated* trials.

Evidence for location or response inhibition is indicated by prolonged responding and possibly lower accuracy in all trials with a location repetition (i.e., *sound-changed, location-repeated* trials and *sound-repeated, location-repeated* trials) as compared with control trials. Responding in *sound-repeated, location-changed* trials should be equal to control trials because prime distractor and probe target appear at different locations which are also assigned to different responses. The difference between trials with a location change and trials without one will be assessed for the three RSIs (600 ms, 1250 ms, and 1,900 ms) to test whether evidence of inhibition has been missed in previous experiments due to temporal dynamics of the inhibitory processes. If an inhibitory after-effect was missed because inhibition decays quickly, then it should be measurable with an RSI of 600 ms or 1250 ms. If an inhibitory after-effect was missed because inhibition takes more time to develop than was previously thought, then it should be measurable with an RSI of 1,900 ms.

In contrast, the feature mismatching hypothesis (Park & Kanwisher, 1994) predicts impaired responding when prime distractor and probe target contain mismatching features. This is the case in *sound-changed, location-repeated* as well as in *sound-repeated, location-changed* trials but not in *sound-repeated, location-repeated* trials. There was no basis for making specific predictions about changes of feature-mismatching effects as a function of the RSI. Thus, the present study is merely exploratory in this respect.

Method

Participants

Of the 28 participants in each group, 17, 20, and 18 were female and their age ranged form 20 to 40 years (*M* = 26), from 19 to 38 years (*M* = 24), and from from 19 to 39 years (*M*

= 26) in the 100-ms, the 750-ms, and the 1,400-ms RSI group, respectively. The experiment was conducted in accordance with the ethical guidelines of the German Psychological Association (DGPs) and the Professional Association of German Psychologists (BDP) (2005, C.III) and with the 1964 Declaration of Helsinki. Participants were tested individually and were either paid or received course credit.

Materials

The stimuli were four digital recordings (sampling rate: 48 kHz) of easily discriminable instrumental sounds (guitar, drum, triangle, and harmonica) which were 400 ms long with 10-ms linear onset-offset ramps. All sounds were presented at an intensity of approximately 64 dB(A) SPL. Participants sat in the middle of a 3.2 × 2 m room with four speakers (JBL Control Pro) placed in a semi-circular arrangement in front of them with an angular disparity of 60° between speakers. The speakers were placed 95 cm away from the participants and were set to a height of 128 cm. For the ease of reference, speaker positions and response keys in Figure 1 are labeled from left to right as L1-L4 and A-D, respectively. A 16-inch monitor was positioned in front of the participants at a distance of 83 cm.

[Insert Figure 1]

Each trial consisted of a prime presentation followed by a probe presentation. At the beginning of each presentation, a picture cue on the monitor indicated the identity of to-be-attended sound. Participants indicated the speaker that emitted the cued sound by pressing an associated key on a response box while ignoring a simultaneously played distractor sound at another location. The speaker-response key assignment was kept spatially compatible: responses to the speakers L1, L2, L3, and L4 required pressing the A, B, C, and D key, respectively. Participants used the index and middle fingers of their left and right hand to operate the response keys.

Trial types were generated as in previous experiments (Mayr et al., 2011; Mayr et al., 2014) by systematically varying location and sound identity features between prime and probe presentations. Target and distractor sounds were always presented from different speakers. Prime target and prime distractor sounds appeared equally often from each speaker location. The same applies to the probe target and probe distractor sounds. The probe distractor sound was always presented from a speaker location that had been unoccupied in the prime presentation. The resulting trials either belonged to the *ignored repetition* or *attended repetition* subdesign. In the ignored repetition subdesign the location repetition between prime distractor and probe target sounds was systematically varied. In the attended repetition subdesign location repetition between prime target and probe target was manipulated. Trials within each subdesign were generated once with and once without a sound identity repetition between successive presentations. For sound-changed trials, target and distractor sounds were randomly chosen for prime and probe with the restriction that all sounds differed from each other. For sound-repeated trials in the attended repetition subdesign, successive target sounds comprised the same sound identity, while sound identity repetitions in the ignored repetition subdesign occurred between prime distractor and probe target sound. This procedure resulted in a total of 48 trials (25 % sound-changed, location-changed, 25 % sound-changed, location-repeated, 25 % sound-repeated, location-changed, and 25 % sound-repeated, location-repeated, respectively) in each subdesign which were quadruplicated and combined to a total of 384 trials that were presented in random order. Figure 2 provides examples of the four trial types in the ignored repetition subdesign.

[Insert Figure 2]

Procedure

Two training phases familiarized participants with the simultaneous sound presentation (Training 1) and the prime-probe-sequence (Training 2). In both phases, participants indicated the location of the target sound by pressing the appropriate response key. Training 1 was composed of 50 randomly selected prime presentations while Training 2 consisted of 12 randomly selected prime-probe sequences drawn from the experimental trials. If 70% of the past 15 trials in Training 1 had been responded to correctly, Training 2 commenced. Participants were offered to quit the experiment or to repeat Training 1 one more time if they failed to achieve this criterion within 50 trials. All participants reached Training 2. After the end of Training 2 the experimental phase started automatically.

Each experimental trial consisted of a prime presentation followed by a probe presentation. At the beginning of the prime presentation, a picture cue indicating the to-be-attended sound was presented at the center of the screen. With a delay of 500 ms (cue-target interval, CTI), two prime sounds were simultaneously presented from different speakers. Responses occurring between 100 ms and 3,000 ms after the sound onset were counted as valid. The cue persisted on the screen until a response had been made or an interval of 3,000 ms had been exceeded. The prime response was immediately followed by a prime-probe interval (PPI) of 100 ms, 750 ms, or 1,400 ms, depending on the experimental group. No visual or auditory stimuli were presented during the PPI. The offset of the PPI initiated the presentations of the visual probe cue, followed by the probe sounds after a CTI of 500 ms. Most important for the present purpose, the response-stimulus interval (RSI) was defined as the time between the prime response and the presentation of the probe sounds in each trial. Therefore, the RSI was composed of the PPI and the CTI in the probe, yielding RSI values of 600 ms, 1,250 ms, and 1,900 ms for the respective experimental group. Valid prime and probe responses had to be given between 100 ms and 3000 ms after sound onset. After the probe response, participants received an audio-visual feedback about the correctness of their responses in the current trial. The next trial started after a 1,000 ms inter-trial interval. After every 12th trial, the experiment paused and participants received a summary feedback of their performance in the previous block. Participants resumed the experiment at their own discretion. After the experiment they were informed about its purpose. The experiment took about 57 min, 63 min, and 66 min for the 600-ms, the 1,250-ms, and the 1,900-ms RSI groups, respectively.

Design

The experiment comprised two subdesigns (ignored repetition, attended repetition), but the ignored repetition subdesign was of primary interest with respect to the mechanisms that operate in non-target events. Both subdesigns comprised a 2 × 2 × 3 mixed design with *sound identity* (repeated vs. changed) and *location* (repeated vs. changed) as within-subject variables and *RSI* (600 ms, 1,250 ms, 1,900 ms) as between-subject variable. The primary dependent variable was participants' average reaction time, but error rates were also analyzed.

Recall that inhibitory processes should impair responding in *sound-changed, location-repeated* and in *sound-repeated, location-repeated* trials relative to *sound-changed, location-changed* control trials, while *sound-repeated, location-changed* trials should not differ from control trials. In contrast, the feature mismatching hypothesis predicts impaired performance whenever the prime distractor does not fully match the probe target—that is, performance should be worse in *sound-changed, location-repeated* trials and in *sound-repeated, location-changed* trials relative to *sound-changed, location-changed* (control) trials , while *sound-repeated, location-repeated* trials should not differ from control trials.Thus, whether there is evidence of inhibition or feature mismatching can be determined by three binary comparisons (*t* tests) comparing performance in the control condition to performance in each of the other three conditions.

However, the primary analysis concerns the effect of the RSI manipulation on sound identity and location effects. We would have to conclude that the RSI does not affect the pattern of results (and thus, whether there was evidence of inhibition or feature mismatch) if there were no significant RSI × sound identity × location interaction. Given $\alpha = \beta = .05$ and a population correlation of $\varrho = .30$ between the reaction time differences of the *location* variable (repeated – changed) in the two levels of the *sound identity* variable, an a priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) revealed that a sample size of $N = 66$ was necessary to detect a three-way interaction effect of size $f = 0.3$ (medium to large effects in terms of Cohen, 1988). We were able to collect data from a total of 84 participants so that the power was even somewhat larger than what we had planned for ($1 - \beta = .99$). The global level of alpha was maintained at .05. All reported *t*-tests for the binary comparisons in the ignored repetition subdesign are two-tailed. The Bonferroni-Holm method (Holm, 1979) was applied to prevent α-error accumulation for the three binary comparisons outlined in the previous paragraph. Following this method, the three binary comparisons were rank-ordered on the basis of their *p*-values, starting with the smallest value. Dividing the global alpha level of .05 by the total number of comparisons set the critical alpha level for the comparison with the smallest *p*-value to $\alpha/3 = .017$. The critical alpha was $\alpha/2 = .025$ for the subsequent comparison while the critical alpha remained at $\alpha/1 = .05$ for the final comparison with the largest *p*-value. For convenience, the critical alpha levels are reported in brackets after the exact empirical *p*-values. Note that, due to the sequential nature of the Bonferroni-Holm method, all rank-ordered comparisons following the first non-significant contrast are treated as non-significant, irrespective of their *p*-value.

Results

Performance was evaluated for probe responses that followed a correct prime response. As the present study is primarily concerned with mechanisms that operate on non-target events, the results of the ignored repetition subdesign were of main importance. However, performance in the attended repetition subdesign was also analyzed because it provides further information with respect to the general mechanism underlying stimulus and response processing in auditory spatial negative priming. Average probe response times and error rates in the ignored repetition subdesign and the attended repetition subdesign are depicted in Figure 3 and Figure 4, respectively.

A 2 × 2 × 3 ANOVA on the latency data with *RSI* as between-subject variable and *sound identity* and *location* as within-subject variables showed that there was no three-way interaction, $F(2, 81) = 1.092$, $p = .340$, $\eta^2 = .026$, reflecting the fact that the pattern of the reaction times did not vary as a function of the RSI. The only statistically significant effect was the *sound identity* by *location* interaction, $F(1, 81) = 38.697$, $p < .001$, $\eta^2 = .323$. All remaining effects did not reach statistical significance, with all $Fs(1, 81) \leq 0.226$, $p \geq .632$, $\eta^2 \leq .003$, for the sound identity and location main effects and interactions and all $Fs(2, 81) \leq 0.461$, $p \geq .632$, $\eta^2 \leq .011$, for the main effects and interactions involving the RSI variable.

Given that the pattern of the reaction times did not vary as a function of the RSI, we simplified the subsequent analyses by collapsing across the RSI variable. For the entire sample we then determined, using the binary comparisons outlined above, whether the data pattern is compatible with the predictions of the inhibition accounts or of the feature mismatching hypothesis. The family of individual *t*-tests revealed a pattern of results compatible with the feature mismatching hypothesis. As compared with *sound-changed, location-changed* control trials, responding was only slowed-down in *sound-repeated, location-changed* trials, $t(83) = 5.161$, $p < .001$ [$p = .017$], $d_z = 0.564$, and in *sound-changed,* *location-repeated* trials, $t(83) = 4.657$, $p < .001$ [$p = .025$], $d_z = 0.508$. In contrast, response latency did not differ between *sound-repeated, location-repeated* and control trials, $t(83) = 0.578$, $p = .564$ [$p = .050$], $d_z = 0.063$.

The results of the error rates mirrored that of the latency data in that there was no reliable three-way interaction, $F(2, 81) = 0.052$, $p = .949$, $\eta^2 = .001$, but a significant *sound identity* and *location* interaction, $F(1, 81) = 22.233$, $p < .001$, $\eta^2 = .215$. There were significant main effects of *sound identity* and *location*, $F(1, 81) = 8.824$, $p = .004$, $\eta^2 = .098$ and $F(1, 81) = 6.124$, $p = .015$, $\eta^2 = .070$, respectively but due to the disordinal nature of the interaction between these two variables (see columns for the whole sample in Figure 3B), both main effects cannot be conclusively interpreted. All remaining effects did not reach statistical significance, all $Fs(2, 81) \leq 2.223$, $p \geq .115$, $\eta^2 \leq .052$.

Binary comparisons were carried out to further analyze the pattern obtained for the error data. Most importantly, the results of the error data did not compromise the interpretation of the latency results. Responding in *sound-changed, location-repeated* trials was not only slowed down but also more error-prone than responding in control trials, $t(83) = 4.849$, $p < .001$ [$p = .017$], $d_z = 0.527$. However, the rate of erroneous responses in *sound-repeated, location-changed* trials was only descriptively, but not statistically, increased relative to control trials, $t(83) = 0.977$, $p = .332$ [$p = .025$], $d_z = 0.104$. Parallel to the latency data, the error rate in *sound-repeated, location-repeated* trials was not different from that in control trials, $t(83) = -0.381$, $p = .704$ [$p = .050$], $d_z = 0.042$.

[Insert Figure 3]

Keep in mind that for trials in the attended repetition subdesign, prime target to probe target repetitions define the different trial types. The same testing rationale was used as in the ignored repetition subdesign.

A 2 × 2 × 3 ANOVA on the latency data in the attended repetition subdesign revealed no three-way interaction between *RSI* as between-subject variable and *sound identity* and *location* as within-subject variables, $F(2, 81) = 2.450$, $p = .093$, $\eta^2 = .057$. There were statistically significant main effects of *sound identity* and *location*, with $F(1, 81) = 227.880$, $p < .001$, $\eta^2 = .738$ and $F(1, 81) = 73.812$, $p < .001$, $\eta^2 = .477$, respectively. Moreover, a significant *sound identity* by *location* interaction was obtained, $F(1, 81) = 160.539$, $p < .001$, $\eta^2 = .665$. All remaining effects did not reach statistical significance, with all $Fs(2, 81) \leq 2.262$, $p \geq .111$, $\eta^2 \leq .053$.

As the pattern of results did not differ between the RSI groups, the data was collapsed across the RSI variable and a family of individual *t*-tests was applied to determine the overall a pattern of results. As compared with *sound-changed, location-changed* control trials, responding was faster in *sound-repeated, location-repeated* trials, $t(83) = -15.563$, $p < .001$ [$p = .017$], $d_z = 1.698$, but was reliably slowed-down in *sound-changed, location-repeated* trials, $t(83) = 3.255$, $p = .002$ [$p = .025$], $d_z = 0.355$. Finally, response latency did not differ between *sound-repeated, location-changed* and control trials, $t(83) = -1.275$, $p = .206$ [$p = .050$], $d_z = 0.139$.

As for the latency results, there was no reliable three-way interaction in the error data, $F(2, 81) = 0.372$, $p = .691$, $\eta^2 = .009$, but a significant *sound identity* and *location* interaction, $F(1, 81) = 101.789$, $p < .001$, $\eta^2 = .557$. There was also a significant main effect of *sound identity,* $F(1, 81) = 43.427$, $p <.001$, $\eta^2 = .349$. All remaining effects did not reach statistical significance, with $F(1, 81) = 3.130$, $p = .081$, $\eta^2 = .037$, for the location main effect and all $Fs(2, 81) \leq 1.013$, $p \geq .368$, $\eta^2 \leq .024$, for the main effects and interactions involving the RSI variable.

Binary comparisons revealed that responding in *sound-repeated, location-repeated* trials was not only facilitated but also less error-prone than responding in control trials, $t(83)$

= -6.240, $p < .001$ [$p = .017$], $d_z = 0.681$. As compared with control trials, more error were committed in *sound-changed, location-repeated* trials as well as in *sound-repeated, location-changed* trials, with $t(83) = 6.172$, $p < .001$ [$p = .025$], $d_z = 0.668$ and $t(83) = 3.257$, $p = .002$ [$p = .050$], $d_z = 0.355$, respectively.

[Insert Figure 4]

Discussion

In contrast to visuospatial negative priming, there is no evidence of location or response inhibition in auditory spatial negative priming tasks. The aim of the present study was to test whether this is so because inhibition occurs in auditory distractor processing under conditions that have not yet been tested. Specifically, the timing of prime and probe events in previous tasks might not have been appropriate to detect inhibitory after-effects. First, inhibition in audition may be so short-lived that it has already dissipated by the time the probe response is generated. Second, the delay between the prime response and the probe target may have been too short for inhibition to increase to a measurable level.

The present study tested these assumptions by using RSIs that were shorter (600 ms and 1,250 ms) or longer (1,900 ms) than the 1,500-ms RSI previously used in auditory spatial negative priming experiments (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014; Möller et al., 2013). If inhibition is particularly short-lived, then, evidence for this mechanism should be observed in the 600-ms RSI group and perhaps in the 1,250-ms group, whereas the effect should be absent in the 1,900-ms RSI group. Alternatively, if inhibition takes time to develop, a spatial negative priming effect might only occur in the 1,900-ms RSI group.

The results of the present experiment are straightforward: First, and in contrast to related findings in the visual modality (Buckolz et al., 2008), the pattern of performance was not affected by the RSI manipulation. The pattern of results in all RSI groups alike indicated that responding was not generally impaired (relative to control trials) when the probe target was presented at the location of the former prime distractor and required the execution of a previously withheld response. Apart from the absence of evidence for inhibition, performance was solely determined by the occurrence of feature mismatches between prime distractor and probe target, leading to delayed responding in *sound-changed, location-repeated* and in *sound-repeated, location-changed* trials, but not in *sound-repeated, location-repeated* trials. Therefore, the present findings provide no evidence for inhibitory distractor processing but further support earlier conclusions that performance in these tasks is solely determined by feature mismatching effects (Mayr et al., 2011; Mayr et al., 2009; Mayr et al., 2014; Möller et al., 2013). The present results also suggest that prime-probe intervals in previous studies were generally appropriate to detect after-effects of distractor processing (i.e., feature mismatching effects) in auditory spatial negative priming.

Together, these results can be used to further specify the mechanisms of distractor processing in audition and are also informative with respect to which features of non-target events are encoded in an integrated episodic representation. The results strongly support the notion that spatial and identity features of irrelevant sound events are stored into an object file. Moreover, the pattern of results fits well to the assumption that the whole content of an object file is retrieved when one of its incorporated features is encountered in a subsequent presentation, leading to impaired performance in the case a partial mismatches between prime distractor and probe target (see Zmigrod & Hommel, 2009; Zmigrod & Hommel, 2010, for a similar conclusion). However, the present results do not indicate that any distractor-related inhibitory processing is encoded in an episodic representation that persists until the corresponding probe presentation.

Alternatively, it might be the case that locations or responses associated with non-target events were actively suppressed to prevent false responding, but this processing did not affect probe performance in the present study. In this vein, current models of visuospatial negative priming assume that inhibitory location or response information attached to the prime distractor is stored in an episodic format and is reinstated when the episode is retrieved by feature repetitions at the time of the probe (e.g., Buckolz, Edgar, Kajaste, Lok, & Khan, 2012; Haworth, Buckolz, & Kajaste, 2014; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992; Tipper, 2001). If comparable processing occurs in auditory spatial negative priming, at least two explanations for the absence of inhibitory after-effects can be considered. It might be that inhibition operates on distractor events during the prime, but that the *outcome* of this process is either (1) not stored or (2) is not (or no longer) retrieved at the time of the probe. With respect to the first variant, several studies investigating binding mechanisms across perception and action suggest that stimulus- and response-related features are more likely to be integrated into a common representation when their respective processing overlaps in time (e.g., Hommel, 2004; Zmigrod & Hommel, 2009, 2010). With respect to prime processing, it might be that identity and spatial features of the distractor sound are rather contemporaneously processed (resulting in a conjoint storage of these features in an object file). However, location or response *inhibition* might occur later during prime processing, presumably due to the "reactive" nature of inhibition denoting that it follows the initial activation of distractor features. The resulting time gap between sound feature processing and inhibition might be too large so that inhibition is not included in the object file containing sound feature representations.

According to the second variant, the outcome of inhibitory processing is actually stored in an episodic fashion, but a failure to retrieve the prime processing episode at the time of the probe causes the absence of inhibitory after-effects. Specifically, the results of the present study strongly suggest that the object file containing sound identity and spatial features of a prime distractor persists until the probe. However, it might be that inhibitory information is likewise stored as part of the prime episode, but quickly decays after the prime (not that his is reminiscent of the starting point of the present study).

To reiterate, the results of Buckolz et al. (2008) suggest that response-related inhibition in vision requires more than 75 ms to affect subsequent performance and can be maintained over an interval of at least 10 s. If the time-course of the inhibitory status (indicated by its after-effect on probe performance) was similar for vision and audition, an auditory spatial negative priming effect should have been present in all RSI groups employed in the present study[3]. However, this was not the case. Based on the present findings, it might be concluded that the episodic representation containing inhibitory location or response processing does not endure an RSI of 600 ms, at least not to an extend that affects responding in the subsequent probe. Alternatively, it is possible that an RSI of 1,900 ms still does not provide enough time to sufficiently inhibit the distractor-assigned location or response. Although both cases are conceivable in principle, the latter is somewhat at variance with a proposed functional property of inhibitory distractor processing. Specifically, it is a widely shared assumption that a main purpose of inhibition is to reduce current activity associated with task-irrelevant events to ultimately prevent false responding (e.g., Band & van Boxtel, 1999; Houghton & Tipper, 1994; Neill & Valdes, 1996; Neumann & DeSchepper, 1991; Ridderinkhof, 2002). It follows that the inhibitory status of a distractor becomes dispensable as soon as a task-appropriate response has been given or distractor events no longer strive for

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[3] Given that after-effects attributed to inhibition in vision require at least 75 ms to emerge but are present, at the latest, after 750 ms following the prime presentation (Buckolz et al., 2008), it might also be possible that reliable performance costs in ignored repetition trials (as compared with control trials) can also be obtained with interval durations in between these values. However, this assumption remains speculative. Therefore, the presumed time-course of distractor response inhibition in the visual modality can only be tentatively applied to the 600-ms RSI in the present study.

the control of action. Therefore, inhibitory processing in the present spatial negative priming task should be triggered by the occurrence of distractor events but should subside after correct responding is achieved. It is rather implausible that the amount of inhibition further *increases* over an interval that follows a correct response and during which no further events call for inhibitory processing. In fact, the results of the “distractor-plus-target” group of Buckolz et al. (2008, Experiment 1) also suggest that inhibitory after-effects decrease (rather than increase) as the time between prime response and probe stimuli increases. Therefore, instead of assuming that inhibitory after-effects emerge with interval beyond 1,900 ms, we favor the possibility that inhibition does not operate in auditory distractor processing at all or that its after-effects do not persist after an RSI of 600 ms. However, any speculations about the after-effects of distractor processing that refer to RSIs other than the ones employed in the present study remain theoretical in nature and have to be addressed by future research.

In sum, the present results do not show any evidence that distractor locations or their task-assigned responses are inhibited, at least not in a way that affects subsequent performance within the present RSI durations. This might indicate that inhibition does not operate on auditory distractor events *per se* or that its after-effect takes a considerably different time-course as compared with related processing in the visual modality. In any case, the present findings suggest that distractor processing (as indicated by the results obtained in spatial negative priming task) differs between vision and audition.

In fact, the present results of the attended repetition subdesign are in favor of the idea that spatial and sound identity information of target events are not encoded and stored individually, but are integrated into a common processing episode. The pattern of results of the attended repetition subdesign is therefore well in line with the object file concept (e.g., Hommel, 1998; Hommel, 2004; Zmigrod & Hommel, 2009, 2010). The formation of object files is indicated by slowed-down and more error-prone responding in *sound-changed,* *location-repeated (*as compared with control trials) that comprise a location-identity mismatch between subsequent presentations (see Park & Kanwisher, 1994, Experiment 4 for a similiar result obtained in visuospatial negative priming). In the same vein, more errors (as compared with control trials) were committed when prime and probe target comprised the same sound but were presented from different speakers (i.e. in *sound-repeated,location-changed* trials) which likewise denotes a location-identity mismatch between successive presentations. However, the response latency did not differ between these trial types which suggests that feature mismatching effects were somewhat more pronounced in the error data. As compared with all other trial types, responding was largely facilitated and less error-prone in *sound repeated, location-repeated* trials that comprised a full repetition between successive target presentations. This facilitative effect has not always been reported in studies concerned with object file binding in audition (e.g., Zmigrod & Hommel, 2009, 2010). Therefore, it might indicate the operation of an additional process, presumably of the so-called *bypass rule* in *sound-repeated, location-repeated* trials in the attended repetition subdesign. The bypass rule (e.g., Fletcher & Rabbitt, 1978; Krueger & Shapiro, 1981) states that participants are inclined to repeat the previously executed response in the case of a complete match between successive target stimuli. This might explain the remarkably good performance in *sound-repeated, location-repeated* trials because solely re-executing the previous target response actually leads to correct performance in these trials. Most important, the results from the attended repetition subdesign further support the notion that sound events are stored in a common representation.

Apart from that, the present results provide strong evidence for feature mismatching effects, supporting the assumption that object files (i.e., combined encodings of identity and location information) are generated for task-irrelevant sounds. It seems to be the case that object files for target and distractor sounds are generated to disentangle relevant and irrelevant aspects interwoven in the conjoint signal of concurrently presented sounds. After spatial and sound identity features are bound into a common representation, the object file associated with the current task-defined target is further processed which ultimately leads to a response. The present result also suggest that object files for irrelevant sounds also are quickly established during prime processing. Otherwise, no feature mismatching effects would have been found in the 600-ms RSI group. The results also demonstrate that object files can be maintained in short-term memory for at least 1,900 ms after the prime response. Together, the present findings nicely add to the growing experimental evidence for object file binding in auditory processing (Dyson & Ishfaq, 2008; Hall, Pastore, Acker, & Huang, 2000; Maybery et al., 2009; Mondor, Zatorre, & Terrio, 1998; Parmentier, Maybery, & Elsley, 2010; Zmigrod & Hommel, 2009, 2010) while inhibitory distractor processing might only affect immediate responding for less than 600 ms or might require more than 1,900 ms to come into play.

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Compliance with Ethical Standards

The authors Malte Möller, Susanne Mayr, and Axel Buchner certify (1) that all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards, (2) that informed consent was obtained from all individual participants included in the study and (3) that they have no affiliations or involvement in any organization or entity with any financial or non-financial interest in the subject matter, materials or results presented and discussed in this manuscript.

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Figure 1. Schematic illustration of the speaker and response key arrangement in the setting of the present experiment. The response keys A, B, C, and D were assigned to the speaker locations L1, L2, L3, and L4, respectively.

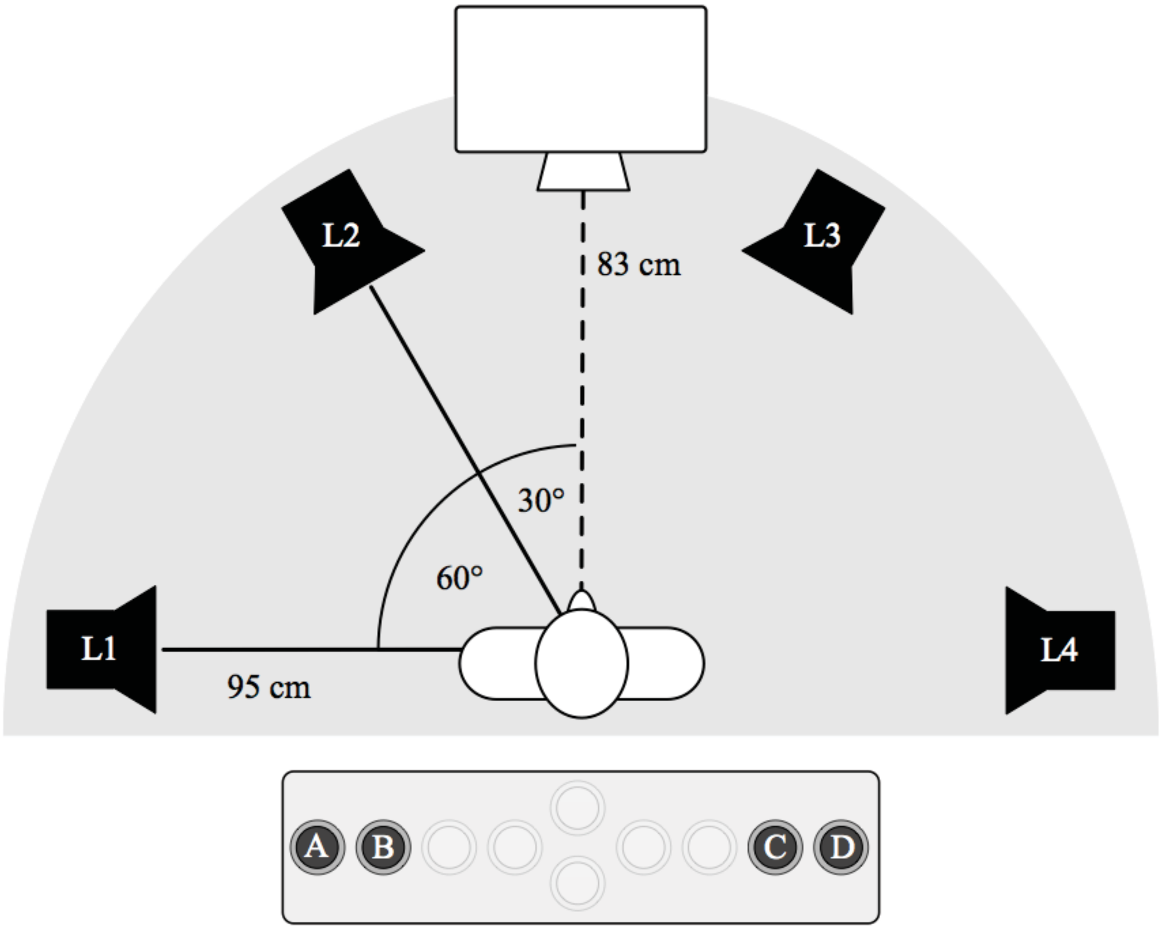


Figure 2. Schematic examples of the four trial types in the ignored repetition subdesign. The to-be-attended instrumental sound is printed in boldface. For the ease of illustration, the visual cue is depicted as a written word and not in a picture format. Correct keypress responses are shown for prime and probe presentations.

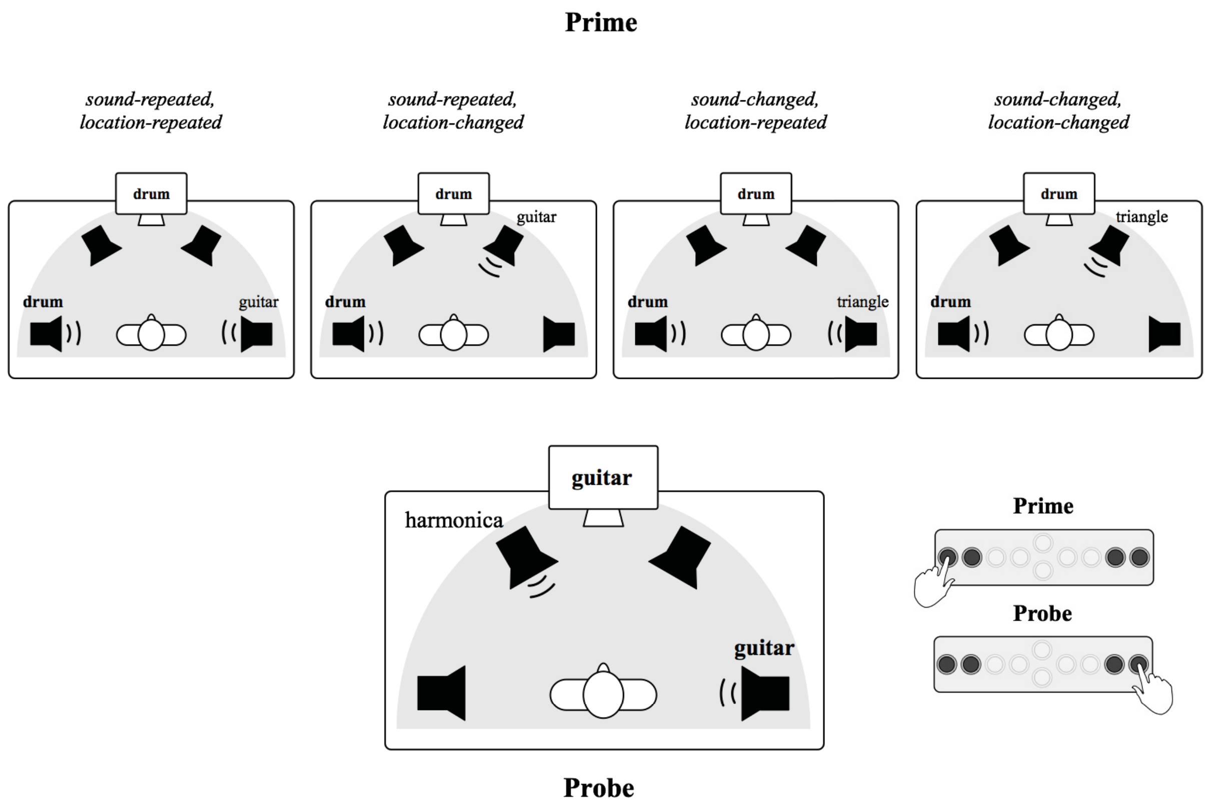


Figure 3. Mean reaction times (A) and error rates (B) for the whole sample and the three RSI groups (600 ms vs. 1,250 ms vs. 1,900 ms) as a function of location (repeated vs. changed) and sound identity (repeated vs. changed) in the ignored repetition subdesign. The error bars depict the standard errors of the means.

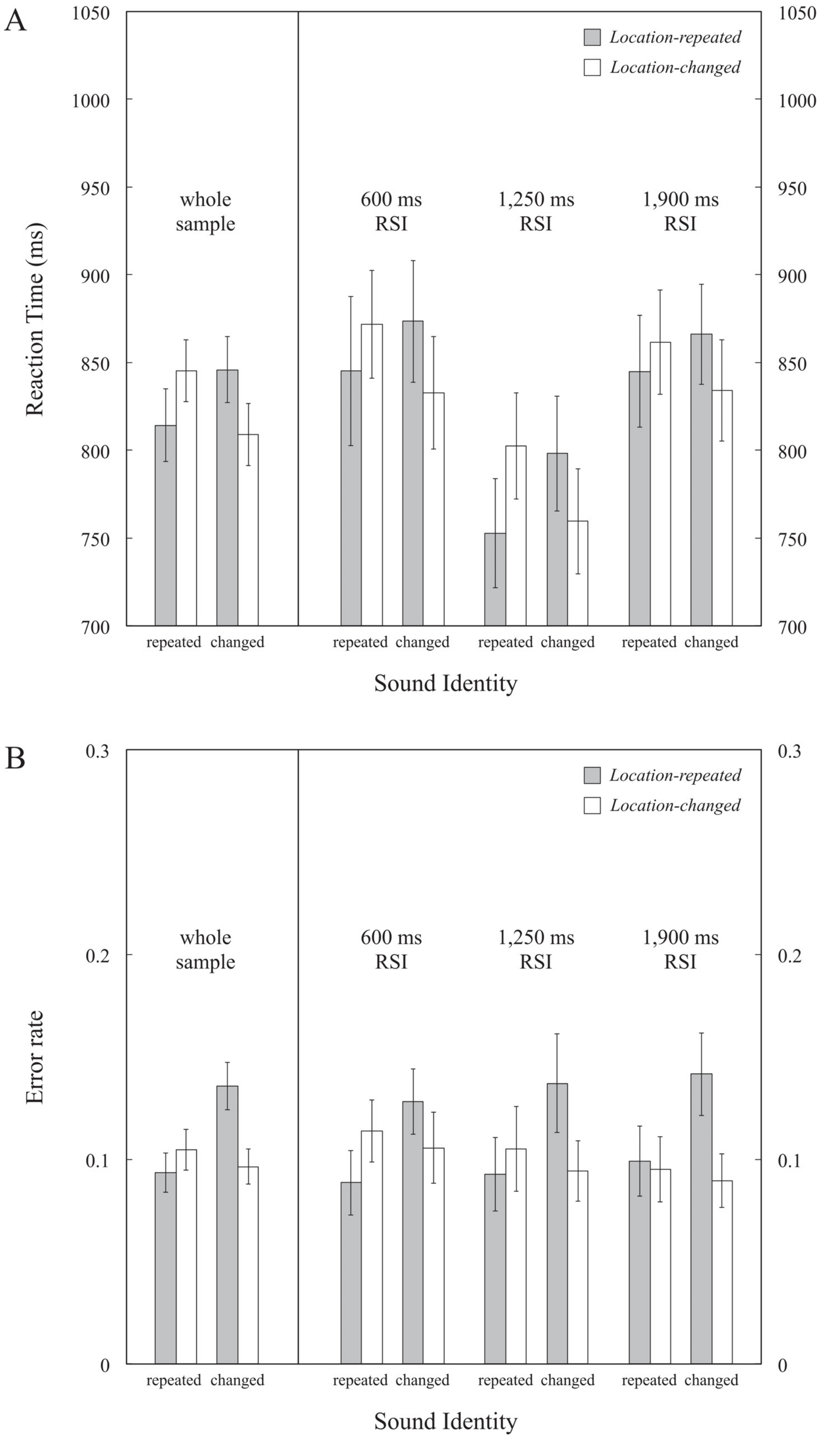
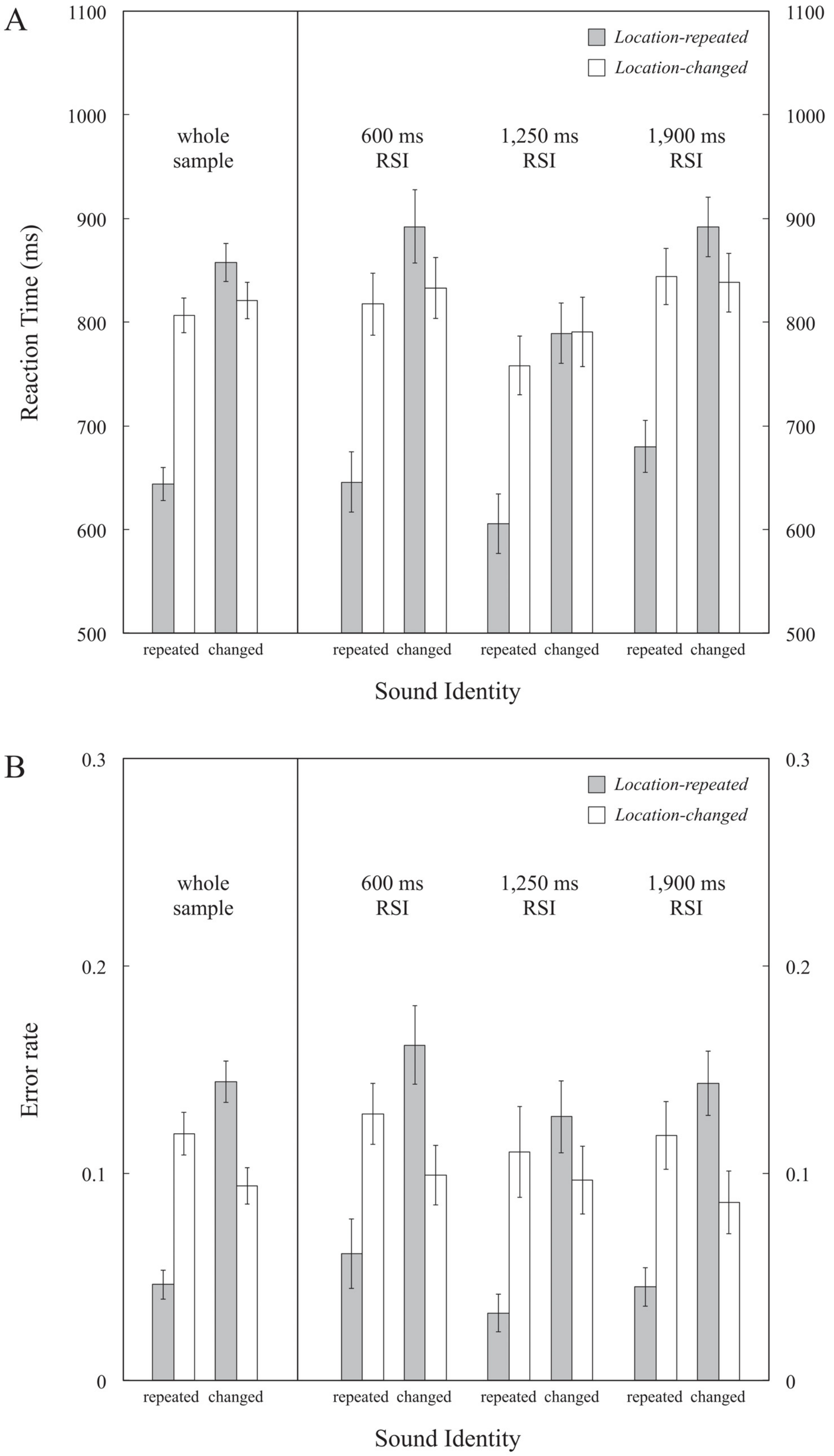


Figure 4. Mean reaction times (A) and error rates (B) for the whole sample and the three RSI groups (600 ms vs. 1,250 ms vs. 1,900 ms) as a function of location (repeated vs. changed) and sound identity (repeated vs. changed) in the attended repetition subdesign. The error bars depict the standard errors of the means.



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Effects of spatial response coding on distractor processing: Evidence from auditory spatial negative priming tasks with keypress, joystick, and head movement responses

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Abstract Prior studies of spatial negative priming indicate that distractor-assigned keypress responses are inhibited as part of visual, but not auditory, processing. However, recent evidence suggests that static keypress responses are not directly activated by spatially presented sounds and, therefore, might not call for an inhibitory process. In order to investigate the role of response inhibition in auditory processing, we used spatially directed responses that have been shown to result in direct response activation to irrelevant sounds. Participants localized a target sound by performing manual joystick responses (Experiment 1) or head movements (Experiment 2B) while ignoring a concurrent distractor sound. Relations between prime distractor and probe target were systematically manipulated (repeated vs. changed) with respect to identity and location. Experiment 2A investigated the influence of distractor sounds on spatial parameters of head movements toward target locations and showed that distractor-assigned responses are immediately inhibited to prevent false responding in the ongoing trial. Interestingly, performance in Experiments 1 and 2B was not generally impaired when the probe target appeared at the location of the former prime distractor and required a previously withheld and presumably inhibited response. Instead, performance was impaired only when prime distractor and probe target mismatched in terms of location or identity, which fully conforms to the feature-mismatching hypothesis. Together, the results suggest that response inhibition operates in auditory processing when response activation is provided but is presumably too short-lived to affect responding on the subsequent trial.

Keywords Auditory · Distractor processing · Attention · Inhibition · Object-binding

Most everyday environments comprise relevant as well as irrelevant information. A major research interest focuses on identifying the mechanisms that allow the cognitive system to deal effectively with the omnipresent influence of irrelevant information in order to allow goal-directed behavior. One rationale for identifying the mechanisms underlying distractor processing is to study the consequences of their operation on future processing. In visuospatial negative priming tasks, participants are asked to localize a target stimulus in the presence of an irrelevant stimulus. Performance is assessed for pairs of successive presentations, a *prime* followed by a *probe.* On so-called *ignored repetition* trials, presenting the probe target stimulus at the location of the former prime distractor is associated with prolonged and, sometimes, more error-prone responding, as compared with *control* trials without any location repetitions. This finding denotes the visuospatial negative priming effect that is widely used to study the mechanisms that prevent irrelevant information from influencing goal-directed behavior (e.g., Chao, 2009; Fitzgeorge & Buckolz, 2008; Milliken, Tipper, & Weaver, 1994; Tipper, Brehaut, & Driver, 1990).

The traditional account used to explain this effect implies that the spatial representations of distractors are actively suppressed in order to facilitate selecting the prime target and that this inhibition persists into the probe presentation (Milliken, Tipper, Houghton, & Lupiáñez, 2000; Tipper et al., 1990). Subsequent responding is impaired when the probe target appears at the (inhibited) former prime distractor location on ignored repetition trials. The response inhibition account (Buckolz, Goldfarb, & Khan, 2004; see also Buckolz, Edgar, Kajaste, Lok, & Khan, 2012; Fitzgeorge, Buckolz, & Khan, 2011) adopts the notion that an inhibitory mechanism prevents

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irrelevant information from gaining access to overt behavior but assumes that distractor-assigned responses, rather than their spatial representations, are suppressed. Relevant and irrelevant prime stimuli are assumed to automatically activate their corresponding responses. Distractor-assigned responses are subsequently inhibited to prevent false responding. On ignored repetition trials, responding to the location of the probe target requires executing the suppressed prime distractor response. Due to the residual response inhibition from the prime, performance is hampered.

Guy and Buckolz's (2007) participants localized a target stimulus presented at one of four horizontally arranged screen locations by manually pressing an associated response key while responses to a distractor at another location had to be withheld. The two locations to the left of fixation were assigned to a common response key. The same was true for the two locations to the right of fixation. With this arrangement, the effect of solely executing a previously withheld response was assessed by presenting the probe target stimulus at a previously unoccupied location that was assigned to the same response key as the former prime distractor. Performance was compared among these so-called response control trials, traditional ignored repetition trials (comprising location as well as response repetition between prime distractor and probe target), and control trials (without any repetitions between prime and probe). Response times did not differ between response control and ignored repetition trials. In both of these trial types, responding was reliably prolonged, as compared with control trials. The finding that the presentation of the probe target at the location of the former prime distractor does not prolong responding beyond the slowing effect of executing the prior distractor response (see also Buckolz, Fitzgeorge, & Knowles, 2012; Buckolz et al., 2004; Fitzgeorge et al., 2011; Guy, Buckolz, & Khan, 2006) is incompatible with the predictions of a location-based inhibition account (Milliken et al., 2000; Tipper et al., 1990) and confirms the response-based inhibition explanation of the visuospatial negative priming effect.

The spatial negative priming paradigm has also been used to investigate auditory distractor processing in spatial scenarios of simultaneously presented sounds. Mayr, Buchner, Möller, and Hauke (2011, Experiment 1) presented two (out of four) animal sounds from two (out of four) spatially distributed speaker positions. Participants had to localize a visually precued sound by pressing a spatially compatible response key. On ignored repetition trials, the probe target was played from the speaker position of the previously ignored prime distractor. Probe localization performance on ignored repetition trials was compared with control trials without a location repetition between successive presentations. In contrast to results from the visual modality, there was no general performance impairment on ignored repetition trials, as compared with control trials. Responding on ignored repetition trials was delayed only when prime distractor and probe target sounds were presented at the same location but mismatched in identity. Performance did not decline when the two sounds presented at the same location matched in identity (for a parallel data pattern, see Mayr, Hauke, & Buchner, 2009).

Furthermore, Möller, Mayr, and Buchner (2013) adopted Guy and Buckolz's (2007) rationale of mapping multiple locations to common response keys and compared performance between control, response control, and ignored repetition trials. Probe target responses with the previously withheld prime distractor response (response control trials) were not reliably slowed down, as compared with control trials. As in Mayr et al. (2011), performance on traditional ignored repetition trials was strongly influenced by sound identity repetition: For trials with a prime-distractor-to-probe-target location repetition, responding was delayed when the prime distractor and probe target differed in sound identity but was facilitated (relative to the appropriate control trials) when their sound identities matched.

Taken together, these results suggest that both location- and response-based inhibition accounts (Buckolz et al., 2004; Milliken et al., 2000; Tipper et al., 1990) cannot be used to explain spatial negative priming in audition. In contrast, the findings are compatible with the feature mismatching hypothesis originally proposed by Park and Kanwisher (1994).

Following this hypothesis, location and identity features of target as well as distractor stimuli are bound into temporary episodic representations, so-called *object files* (Kahneman, Treisman, & Gibbs, 1992; Treisman, 1993; Treisman & Gelade, 1980), which are stored in short-term memory and retrieved if any aspect of the object file is subsequently encountered. For example, if the front left speaker emits a harmonica sound as the target while the rear right speaker concurrently emits an irrelevant guitar sound, object files are generated for both events ("front left, harmonica" and "rear right, guitar," respectively). If, at the time of the probe, the rear right speaker emits a target sound (e.g., "snare drum"), then this leads to the retrieval of the object file that had been associated with this specific position during the prime. In this example, the retrieved object file "rear right, guitar" conflicts with the current processing of the probe target sound ("rear right, snare drum"). According to the feature-mismatching hypothesis, the cognitive system detects the sound identity mismatch at the rear right position, followed by a time-consuming updating process of the relevant object file, which delays responding. This process does not occur when the retrieved object file matches the probe target. Interestingly, Mayr et al. (2011, Experiment 1) reported another case of feature mismatch in their auditory versions of the spatial negative priming task. Performance was also impaired when prime distractor and probe target were identical sounds appearing at different locations. In sum, retrieved object files impair performance whenever they contain information that does not fully match processing demands posed by the probe target (see also Zmigrod & Hommel, 2009, 2010).

Note that the feature-mismatching hypothesis had also been tested in the visual modality. However, initial evidence in favor of this hypothesis (Park & Kanwisher, 1994, Experiment 4) was countered by studies finding reliable visuospatial negative priming effects even without feature mismatch (Milliken et al., 2000; Tipper, Weaver, & Milliken, 1995). Thus, while feature mismatch detection can affect behavior, it is only of minor importance in the visual modality. Inhibition of distractor-assigned responses seems to be the major factor in visuospatial negative priming. In contrast, all previous studies of auditory spatial negative priming solely supported the feature-mismatching hypothesis but revealed no evidence for the inhibition of distractor responses (Mayr et al., 2011; Mayr et al., 2009; Möller et al., 2013).

On the basis of the apparent differences between the two modalities, the question arises as to whether spatial negative priming in particular and goal-directed behavior in general are ruled by fundamentally different mechanisms in the auditory, as opposed to the visual, modality. Alternatively, it is possible that the inhibition of distractor responses also operates in the auditory modality but that the previous experiments on auditory spatial negative priming were inappropriate to provide evidence for a response inhibition mechanism.

Previous research indicates that the amount of inhibition devoted to a distractor is positively related to its initial strength of activation (e.g., Grison & Strayer, 2001; Houghton, Tipper, Weaver, & Shore, 1996; Schuch, Bayliss, Klein, & Tipper, 2010; Wyatt & Machado, 2013), supporting the notion that inhibitory processes operate reactively (e.g., Houghton & Tipper, 1994). In the same vein, previous research suggests that distractor-assigned response suppression only takes place if irrelevant responses are actually activated and strive for the control of action (Burle, Possamaï, Vidal, Bonnet, & Hasbroucq, 2002; Ridderinkhof, 2002; Schlaghecken & Eimer, 2002). Thus, a sufficient activation of distractor-assigned responses may be the prerequisite for finding response-related inhibitory aftereffects. There is ample behavioral and electrophysiological evidence that visual processing goes along with distractor-related response activation in experimental paradigms such as the well-known flanker and Simon tasks (Buckolz, O'Donnell, & McAuliffe, 1996; Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; De Jong, Liang, & Lauber, 1994; Eriksen, Coles, Morris, & O'Hara, 1985; Ridderinkhof, 2002; Smid, Mulder, & Mulder, 1990; Valle-Inclán & Redondo, 1998), as well as the negative compatibility task (Eimer, 1999; Eimer & Schlaghecken, 2003; Eimer, Schubö, & Schlaghecken, 2002). In a typical Simon task, each trial comprises a single stimulus presented to the left or right of fixation. Responses (“left”/“right”) are arbitrarily assigned to a nonspatial stimulus feature such as color or form. In the flanker and the negative compatibility tasks, target and distractor are simultaneously or sequentially presented, and distinct responses are assigned to each stimulus. Performance is usually compared between so-called *congruent* and *incongruent* trials. On congruent trials, the response that corresponds to nontarget aspect of the presentation (i.e., the stimulus location in the Simon task and the response assigned to the distractor stimuli in flanker and negative compatibility tasks) is demanded by the target information of the display, whereas these responses differ on incongruent trials. Faster and less error-prone responding on congruent, as compared with incongruent, trials is ascribed to an automatic response activation triggered by nontarget information that facilitates the execution of the specific response in the former but delays correct responding on the latter trials. For the visual modality, it thus seems safe to assume that distractor responses are activated, which is a prerequisite for their later inhibition.

The involvement of distractor-related response activation is less clear in the auditory modality. The auditory version of the Simon task (e.g., Buetti & Kerzel, 2008; Leuthold & Schröter, 2006; Simon, Hinrichs, & Craft, 1970; Simon & Small, 1969; Wascher, Schatz, Kuder, & Verleger, 2001; for a review, see Simon, 1990) provides controversial findings with respect to manual response activation triggered by spatially presented sounds. Wascher et al. conducted a series of experiments using a Simon task with visual and auditory stimuli. In the visual version of the task, participants responded to the identity of a letter (A or B) by pressing a left or right response key with the index finger of the corresponding hand. In the auditory version of the task, participants categorized the pitch of a sound (high or low) by pressing the left or right response key. The visual and the auditory stimuli were presented left or right of the vertical meridian, but location was irrelevant for accomplishing the task. The analysis of the lateralized readiness potential—an EEG potential reflecting hand-specific response preparation over the motor cortex (Coles et al., 1985; De Jong, Wierda, Mulder, & Mulder, 1988)—revealed that manual responses ipsilateral to the task-irrelevant stimulus location were activated for visual, but not for auditory, stimuli. On the basis of these findings, the authors proposed that visuospatial stimuli directly activate their spatially corresponding manual responses but auditory stimuli do not. The authors also suggested that the processing of visuospatial stimuli is strongly linked to manual responding to achieve precise spatially directed movements like reaching or grasping (e.g., Crammond & Kalaska, 1994; Georgopoulos, 1997), whereas auditory stimuli have no direct access to the manual motor system—hence, their limited benefit in controlling spatially directed manual operations (see also Barfield, Cohen, & Rosenberg, 1997; Wickens, Sandry, & Vidulich, 1983; Wickens, Vidulich, & Sandry-Garza, 1984; but see Leuthold & Schröter, 2006).

On the basis of the results of Wascher et al. (2001), it is possible to explain why response inhibition seems to occur in visual, but not in auditory, spatial negative priming tasks: If response inhibition depends on the initial activation of distractor responses and the degree of activation is influenced by the interplay of stimulus modality and response type, then manual keypress responses to visuospatial distractors should be activated and, presumably, suppressed to prevent false responding. Manual keypress responses to auditory distractors might not be sufficiently activated to call for inhibition, which is why no aftereffect of response inhibition is found. All previous studies of auditory spatial negative priming used static keypress responses (Mayr et al., 2011; Mayr et al., 2009; Möller et al., 2013). It is thus unclear whether response inhibition does not operate in the auditory modality at all or whether distractor-assigned keypress responses are simply not sufficiently activated by auditory stimuli.

The present study was intended to decide between these two alternatives. To this end, we conceptually replicated the auditory spatial negative priming experiment of Mayr et al. (2011, Experiment 1). In addition to keypress responses, we investigated joystick responses (Experiment 1) and head movements toward the target sound source (Experiment 2). For both response modalities, independent evidence indicates that direct response activation occurs to irrelevant spatial sounds (see below). If response inhibition operates in auditory processing, distractor-related response activation should be suppressed, thereby prolonging the execution of that specific response to the target in the subsequent probe presentation. Thus, a spatial negative priming effect should be found for joystick and head movement responses. In contrast, the absence of a spatial negative priming effect with joystick and head movement responses would suggest that response inhibition is not involved in preventing distractors from gaining access to behavior in a way that delays executing subsequent responses.

Experiment 1

Wiegand and Wascher (2007a) proposed that direct response activation is triggered whenever stimuli and responses are encoded with respect to a common feature—for example, with respect to their position in space. This is typically the case in the horizontal Simon task where visual stimuli that appear on the left or right side of fixation have to be classified on the basis of a nonspatial feature such as shape. When response keys are operated with the left and right hands, responses are assumed to be coded as "left" and "right" due to the anatomical status of the hands. As a consequence, left and right hand responses are directly activated by the experimental stimuli that are likewise coded as "left" and "right"—in this case, on the basis of their (albeit task-irrelevant) position on the display (Wiegand & Wascher, 2005, Experiment 1). The case is different for vertically aligned stimuli. With vertically aligned stimuli, visuomotor activation is typically not elicited by irrelevant spatial stimulus features when two vertically aligned response keys have to be operated by fingers of different hands (Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005; Wiegand & Wascher, 2005, 2007b). With vertically aligned stimuli and bimanual responses, the irrelevant stimulus code ("above," "below") does not correspond to the spatial code of the hand response ("left," "right") so that no direct motor activation occurs. However, Wiegand and Wascher (2007a, Experiment 3) found that stimuli presented above or below fixation directly activated their spatially corresponding responses when participants had to respond by moving one hand away from a central starting position to press one of two vertically aligned response keys. The authors reasoned that, in contrast to keypress responses performed with the left and right hands, spatially directed responses—for example, turning a steering wheel, operating the handle of a joystick, or moving a hand to depress a distant response key—are coded in terms of their movement direction (i.e., "upward" and "downward,"respectively; see Dittrich, Rothe, & Klauer, 2012; Guiard, 1983). As a consequence, spatial stimulus and response codes now largely overlapped ("above," "upward" and "below," "downward") so that direct motor activation occurred. These results suggest that the occurrence of direct motor activation depends on the specific arrangement of stimuli and responses and the way both are coded in the task (see also Fitts & Seeger, 1953). In particular, spatially directed movement responses seem to have a stronger capacity to elicit direct response activation than do static keypress responses when they have to be executed in response to spatial stimuli.

In line with Wiegand and Wascher's (2007a) reasoning, Buetti and Kerzel (2008) provided evidence of direct response activation in audition when spatially directed unimanual movements, instead of static bimanual keypress responses, were used. Participants responded to the pitch (high vs. low) of a 200-ms tone presented from one of two speakers placed to the left and right of fixation. Sound location was irrelevant to the task. Participants indicated the pitch of the presented tone by lifting their right index finger from a central starting position and moving it to the left or right to contact a designated area on the left or right of a touch screen. Longer response times and higher error rates for incongruent, as compared with congruent, trials were found, denoting the typical Simon effect. Importantly, a detailed analysis of the pointing angle indicated that the initial movement on incongruent trials (e.g. when a sound on the left side required a movement to the right) were actually directed toward the task-irrelevant (in this case, left) location of the sound, veering away from the correct response side. The authors concluded that direct response activation of manual responses is not restricted to the visual modality but can actually be triggered by spatially presented sounds when spatially directed movement responses are required.

In the present Experiment 1, participants moved a joystick toward the speaker from which the target sound was played while ignoring a distractor sound at another location. We employed this response mode because (1) joystick movements comprise salient spatial features and are encoded in terms of their movement direction (e.g., Dittrich et al., 2012) and (2) the spatial coding of joystick movements overlaps with the way spatial sound sources are represented because the joystick has to be moved toward the speaker location. Consequently, the high degree of correspondence between the spatial coding of directed unimanual joystick responses and the spatial features of the sounds suggests that the distractor sounds activate their associated responses (in analogy to Buetti & Kerzel, 2008; Wiegand & Wascher, 2007a). According to a response inhibition account (e.g., Buckolz et al., 2004), distractor response activation should be inhibited to prevent the execution of the activated distractor response.

In spatial negative priming tasks, each location is typically assigned to a distinct response key so that a location repetition between prime distractor and probe target always includes the execution of the withheld prime distractor response. Therefore, if activated joystick responses to distractor sounds are actually inhibited, prolonged reaction times and, possibly, higher error rates are predicted for trials with a location (and therefore, response) repetition between prime distractor and probe target. In order to test this prediction, half of the trials in Experiment 1 included a prime distractor-to-probe target location repetition, while the other half of the trials were devoid of it. Given that existing findings on spatial negative priming in the auditory modality (Mayr et al., 2011; Mayr et al., 2009; Möller et al., 2013) revealed a pattern of results compatible with the feature-mismatching hypothesis (Park & Kanwisher, 1994), prime-to-probe sound identity repetition was also manipulated. The orthogonal manipulation of the sound identity and location repetition variable resulted in four different types of trials. *Sound-changed, location-changed* trials were devoid of any repetitions between successive presentations and served as control trials. The sound identity, but not the sound location, was repeated between prime distractor and probe target in *sound-repeated, location-changed* trials, whereas the spatial position, but not the identity, was repeated in *sound-changed, location-repeated* trials. Prime distractor and probe target were identical with respect to both features in *sound-repeated, location-repeated* trials.

The response inhibition account predicts prolonged responding and possibly lower accuracy on all trials with a location repetition (i.e., sound-changed, location-repeated trials and sound-repeated, location-repeated trials), as compared with control trials, but responding on sound-repeated, location-changed trials should be equal to control trials because prime distractor and probe target require different responses. In contrast, the feature-mismatching hypothesis predicts impaired responding when prime distractor and probe target contain mismatching features. This is the case on sound-changed, location-repeated as well as on sound-repeated, location-changed trials but not on sound-repeated, location-repeated trials.

The findings in the joystick group were compared with the data of a parallel group of participants that was exposed to the identical stimulus presentation but had to respond to the target sound location by manually pressing an assigned response key. For the keypress response group, we expected a pattern of results compatible with the feature-mismatching hypothesis, replicating the findings of Mayr et al. (2011, Experiment 1).

Method

Participants

Data of 80 participants were collected, 40 in each response mode group to which they were assigned at random, with the restriction that, at the end of the experiment, an equal number of participants had to be in both groups. Participants in the joystick condition (27 females) ranged from 19 to 40 years (M=25). Participants in the keypress condition (24 females) ranged in age from 20 to 37 years (M=25). One participant in the joystick group and 4 participants in the keypress group reported being left-handed. Participants were tested individually and either were paid or received course credit.

Materials

The stimuli were four easily discriminable instrumental sounds (guitar, drum, triangle, harmonica), digitally recorded at a rate of 48 kHz and cut to a length of 400 ms with 10-ms linear onset–offset ramps. All sounds were presented at an intensity of approximately 63 dB(A) SPL. Participants sat in the middle of a 2.5×3.5 m chamber, 83 cm in front of a 16-in. LCD monitor with a display resolution of 1,280×1,024 pixels. The center of the screen was positioned at a height of 113 cm. The seat was individually adjusted so that the participants' ear level was maintained at a height of approximately 128 cm. Four speakers (JBL control pro) were placed in a semicircular arrangement at a distance of 95 cm around the participant and were separated by 60° from each other (see Fig. 1). Speaker height was set to 128 cm to conform to the approximate ear height of sitting participants. For the ease of reference, speaker positions in Fig. 1 are labeled as L1–L4 from left to right, and the keys of the response box in Fig. 1 are labelled L1–L4, accordingly.

Each trial consisted of a prime and a probe presentation. At the beginning of each presentation, the target sound was cued by a picture of the appropriate instrument, followed by the presentation of two simultaneous sounds from different speakers. In the keypress group, participants indicated the

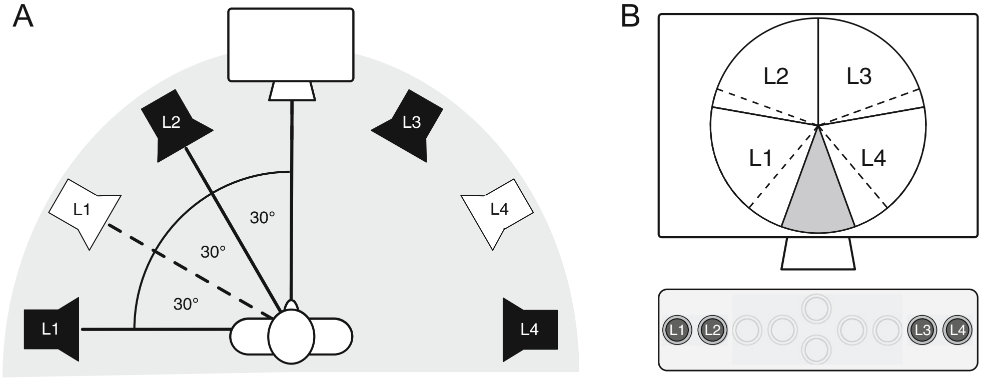

Fig. 1 **a** Schematic illustration of the experimental setting. The arrangement of the speakers in Experiment 1 is indicated by the black speaker symbols. The arrangement was modified in Experiment 2. The positions of the speakers L1 and L4 in Experiment 2 are indicated by the white speaker symbols. **b** Partitioning of the virtual circle into valid response segments for the cursor movements in the joystick condition of Experiment 1 (straight lines). The gray area was not assigned to a speaker. Segment boundaries were slightly changed for the categorization of the head movement responses in Experiment 2 (dashed lines). The assignment of response keys to speaker locations is shown in the lower part of panel b

location of the target sound by pressing one of four horizontally aligned keys on a response box. The assignment of the speakers to the response keys was kept spatially compatible; that is, responses to the speakers L1, L2, L3, and L4 required pressing the L1, L2, L3, and L4 key, respectively. Participants used their right and left middle and index fingers to operate the response keys.

Participants in the joystick group moved a joystick (Attack 3, Logitech GmbH, Munich, Germany) with their dominant hand toward the speaker that emitted the target sound while ignoring the distractor sound. The joystick was located on the table directly in front of the participant. Its handle could be moved in all directions (360°). The joystick handle was mechanically retracted to a central position when no force was exerted on it. Participants had to move the joystick directly to the left or right in order to respond to the speaker locations L1 and L4, respectively. Likewise, the joystick handle had to be pushed diagonally to the left or right to respond to the speaker positions L2 and L3. The displacement of the joystick was translated into a spatially corresponding change of the mouse cursor position on the screen (implemented by the Joystick2Mouse 3.0 software). The *x*-, *y*-coordinates of the mouse cursor were recorded by the experimental software (LiveCode 5.5.3, Runtime Revolution Ltd., Edinburgh, Scotland) with a sampling rate of 60 Hz. The cursor was invisible during the whole experiment. The starting position of the joystick corresponded to a cursor position at the center of the screen. A response was registered when a joystick movement displaced the mouse cursor by more than 400 pixels in any direction away from the central coordinate of the screen. The coordinates at which the mouse cursor exceeded the 400-pixel radius were used to determine the direction of the joystick movement. To this end, a virtual circle around the central coordinate was divided into four equally sized segments of 80°, each of which corresponded to a different speaker. Cursor movements that exceeded the 400-pixel criterion within the segments L1, L2, L3, and L4, were defined as valid responses to the speakers L1, L2, L3, and L4, respectively (see Fig. 1). The remaining segment of 40° (gray in Fig. 1b) was not assigned to a speaker. Responses within this segment occurred very infrequently (0.7 % of all presentations) and were excluded from the statistical analysis.[1]

Trial types were generated for the ignored repetition and the attended repetition subdesign. Within the ignored repetition subdesign, sound identity and location repetitions were systematically varied between prime distractor and probe target, whereas in the attended repetition subdesign, feature repetitions were systematically manipulated between prime target and probe target. The attended repetition subdesign was implemented only to prevent that probe presentations could be predicted on the basis of prime information. There was no substantial hypothesis associated with this subdesign. For the sake of brevity, no analyses of this subdesign will be reported.

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[1] All parameters (i.e., the radius of the virtual circle as well as the size and the boundaries of the response segments) were determined on the basis of extensive prior testing to optimize the measurement of joystick responses and, to anticipate, head movement responses in Experiment 2. But note that the choice of parameters has an effect on the overall performance level. For example, the critical response radius of the virtual circle in Experiment 1 was set to 400 pixels. Had we used a larger radius as the response criterion, response times would have been longer because the response criterion would have been reached later. Similarly, global error rates are influenced by the size and the boundaries of the segments that define valid responses for each speaker, with narrower segments leading to increased error rates. But note that absolute keypress latencies are similarly influenced by arbitrary properties of the measurement device, such as the force necessary to trigger a keystroke. While absolute response times and error rates can be compared neither between keypress and joystick responses (Experiment 1) nor between keypress responses and head movements (Experiment 2), it is possible to compare the overall pattern of results between the response mode groups, which is diagnostic for the underlying processes.

For the ignored repetition subdesign, half of the trials featured a location repetition between the prime distractor and the probe target, whereas prime distractor and probe target were presented at different locations on the remaining trials. Sound identity was orthogonally manipulated between prime distractor and probe target. The prime distractor's sound identity was used as the probe target identity on half of the trials, whereas no sound identity repetition occurred between prime distractor and probe target for the remaining trials. As a result, 25 % of the trials comprised a location repetition, as well as a sound identity repetition, between prime distractor and probe target (sound-repeated, location-repeated), 25 % comprised a sound identity repetition but no location repetition (sound-repeated, location-changed), and 25 % of the trials comprised a location repetition between prime distractor and probe target while the sound identity differed (sound-changed, location-repeated). On the remaining 25 %, neither a location nor a sound identity repetition occurred between prime and probe presentations (sound-changed, location-changed). Trials without repetitions between successive presentations were treated as *control* trials and were compared with the remaining trial types to assess the influence of sound identity and location repetition on performance.

Trials in the ignored repetition subdesign were generated under the following restrictions. First, for a location-repeated trial, the prime distractor was presented at the location of the probe target. Second, the attended prime location differed from the ignored probe location. Parallel location-changed trials were constructed by presenting the prime distractor sound at the only remaining location that did not contain a stimulus in the appropriate location-repeated trials. This procedure yielded 24 individual trials, 12 location-repeated trials, and 12 location-changed trials, which were quadruplicated. In a second step, sound identity information was added. For sound-repeated trials, the sound identity of the probe target was used as the prime distractor sound, whereas no further sound repetition between prime and probe occurred. Sound-changed trials were constructed by randomly selecting sound identities as target and distractor sounds in prime and probe, with the restriction that different sounds had to be presented within and between successive prime and probe presentations. In sum, 192 trials were constructed for the ignored repetition subdesign, with 48 trials in each factorial combination of location (repeated vs. changed) and sound identity (repeated vs. changed) repetition. The same rationale was used to construct 192 trials in the attended repetition subdesign. The 384 trials were presented in random order.

Procedure

During instruction, participants were familiarized with the different sounds and speaker positions, as well as the response mode they had been assigned to. Two training phases were administered to attune participants to the general localization task (training 1) and to familiarize them with successive prime–probe presentations (training 2). In both phases, the to-be-localized sound was cued by a picture of the appropriate instrument on the computer screen. Training 1 consisted of a maximum of 60 randomly selected prime presentations from the set of experimental trials. Participants proceeded to training 2 if they responded correctly on at least 75 % of the past 15 trials. Training 2 comprised a maximum of 60 randomly selected prime–probe sequences from the set of the experimental trials. Again, training 2 was passed if participants had responded correctly on at least 75 % of the past 15 trials. All participants reached the learning criterion in both phases.

The timing of a trial was identical for both response modes. A fixation cross was presented at the center of the screen. At the beginning of each trial, the fixation cross was replaced with the visual cue indicating the to-be-attended instrument. After 500 ms, two prime sounds were simultaneously presented. The visual cue remained on the screen until a response was made or an interval of 3,000 ms had been exceeded. Subsequently, the fixation cross was again presented for 1,000 ms. Then the visual probe cue appeared for another 500 ms before the onset of the probe sounds. Audiovisual feedback about the correctness of both responses was given for 1,000 ms, followed by an intertrial interval of 1,000 ms. A break was provided after every block of 12 trials containing feedback about accuracy and response speed in the current block. Participants continued at their own discretion.

Design

The experiment comprised a 2×2×2 design with *sound identity repetition* (repeated vs. changed) and *location repetition* (repeated vs. changed) as within-subjects variables and *response mode* (joystick vs. keypress) as between-subjects variable. The primary dependent variable was participants' average reaction time, but error rates were also analyzed.

A power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) showed that given $\alpha=\beta=.05$ and a sample size of $N=40$, effects of size $d_z=0.50$ (medium effects in terms of Cohen, 1988) between sound-changed, location-changed control trials, and each remaining trial type could be detected with a power of $1-\beta=.93$ for each response mode. The global level of alpha was maintained at .05. The Bonferroni–Holm method (Holm, 1979) was applied to prevent α-error accumulation for the three planned comparisons (control trials vs. sound-changed, location-repeated trials, sound-repeated, location-changed trials, and sound-repeated, location-repeated trials). All *t*-tests for the planned comparisons are one-tailed.

Results

Probe responses were evaluated only when they followed a correct prime response so that 9.5 % and 8.0 % of the hypothesis-relevant trials in the ignored repetition subdesign were excluded from the statistical analysis in the joystick and keypress groups, respectively. Planned comparisons were carried out separately for the two response modes. Following the Bonferroni–Holm method (Holm, 1979), *p*-values for the three hypothesis-relevant comparisons were arranged in ascending order, starting with the smallest value. Dividing the global alpha level of .05 by the total number of comparisons adjusted the critical alpha level for the comparison associated with the smallest *p*-value to $\alpha/3$=.017. The critical alpha was $\alpha/2$=.025 for the subsequent comparison, and it remained at $\alpha/1$=.05 for the final comparison with the largest *p*-value. Due to the sequential nature of the Bonferroni–Holm method, all rank-ordered comparisons following the first nonsignificant contrast are treated as nonsignificant, irrespective of their *p*-value. All test statistics for the paired comparisons are reported in Table 1. Mean response times and error rates of joystick and keypress responses in the ignored repetition subdesign are shown in Fig. 2.

The reaction time analysis for joystick responses in the ignored repetition subdesign revealed that, as compared with control trials, responding was reliably prolonged on sound-changed, location repeated and sound-repeated, location-changed trials. Responding on sound-repeated, location-repeated trials was facilitated, as compared with control trials. Error rates on sound-changed, location-repeated trials were reliably higher than those on control trials. Accuracy on sound-repeated, location-changed trials did not differ from accuracy on control trials. The same was true for sound-repeated, location-repeated trials.

For keypress responses, the pattern of results was essentially the same. Responding was slower and more error-prone whenever the trial contained a mismatch between prime distractor and probe target—that is, on sound-repeated, location-changed trials and sound-changed, location-repeated trials. Reflecting the fact that the pattern for the latency and accuracy results did not differ between the response modes, there were no interactions involving the response mode factor, all *Fs*(1, 78)≤2.689, *p*≥.105, $\eta^2\leq.033$.

Discussion

Experiment 1 focused on whether responding to previously irrelevant information is influenced by the specific manual response type in a localization task. The results are clear: Keypress latencies and error rates were not generally increased when the probe target was presented at the former prime distractor location and required the execution of a previously withheld response. Instead, performance in the keypress group was solely determined by the occurrence of feature mismatches between prime distractor and probe target: Responding was impaired on sound-changed, location-repeated and sound-repeated, location-changed trials, as compared with sound-changed, location-changed control trials, and it was not impaired on sound-repeated, location-repeated trials in which the probe target fully matched the former prime distractor. The results of the keypress group thus replicate previous findings (Mayr et al., 2011; Mayr et al., 2009; Möller et al., 2013) in that they clearly contradict the predictions of an inhibition account of auditory spatial negative

Table 1 Statistical results and critical alpha levels for each comparison of Experiment 1

Experiment 1 (N=80, $n_{\text{Joystick}}=n_{\text{Keypress}}$=40)									
		Joystick Responses							
		Reaction Times (ms)				Error Rate			
Effect (Trial Type – Control)	*df*	*t*	*p*	α_{critial}	d_z	*t*	*p*	α_{critial}	d_z
Sound-changed, location-repeated	39	**3.647**	**.001**	**.017**	**0.577**	**4.337**	**<.001**	**.017**	**0.686**
Sound-repeated, location-changed	39	**2.098**	**.021**	**.025**	**0.332**	0.442	.331	.025	0.070
Sound-repeated, location-repeated	39	**−1.725**	**.046**	**.050**	**0.273**	0.347	.366	.050	0.055
		Keypress Responses							
		Reaction Times (ms)				Error Rate			
Effect (Trial Type – Control)	*df*	*t*	*p*	α_{critial}	d_z	*t*	*p*	α_{critial}	d_z
Sound-changed, location-repeated	39	**2.139**	**.020**	**.025**	**0.338**	**3.910**	**<.001**	**.017**	**0.618**
Sound-repeated, location-changed	39	**3.065**	**.002**	**.017**	**0.485**	**2.556**	**.008**	**.025**	**0.404**
Sound-repeated, location-repeated	39	**−1.913**	**.032**	**.050**	**0.303**	−0.197	.423	.050	0.031

Note. Test statistics of the paired-sample *t*-tests (*t*, *p*, and α_{critical}) and effect sizes (d_z) for probe reaction times and error rates for joystick (upper panel) and keypress (lower panel) responses in Experiment 1. Sound-changed, location-changed trials served as control for all comparisons. Significant effects (with respect to the critical α-level determined by the Bonferroni–Holm correction) are printed in bold.

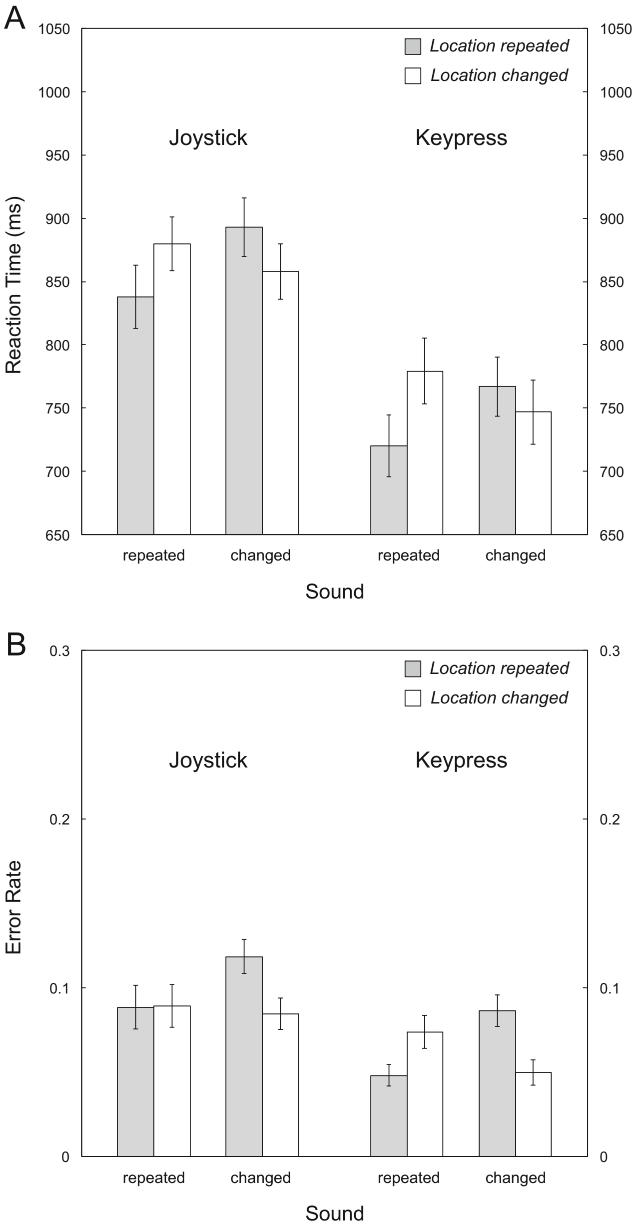

Fig. 2 Mean reaction times (**a**) and error rates (**b**) for joystick and keypress responses as a function of location repetition (repeated vs. changed) and sound repetition (repeated vs. changed) in the ignored repetition subdesign of Experiment 1. The error bars depict the standard errors of the means

priming (e.g., Buckolz et al., 2004), while at the same time supporting the feature-mismatching hypothesis (Park & Kanwisher, 1994).

The spatially directed movement responses in the joystick group can be assumed to lead to direct response activation by a spatial distractor sound (see Buetti & Kerzel, 2008; Wiegand & Wascher, 2007a). If response activation was countered by response inhibition in order to prevent false responding in the prime, performance should have been impaired when the probe target required the execution of the former distractor-assigned joystick movement. This prediction was not confirmed. As compared with control trials, there was no general disadvantage of executing a previously withheld response. Moving the joystick toward the target speaker was delayed only when prime distractor and probe target mismatched with respect to sound identity or location on sound-changed, location-repeated trials, as well as on sound-repeated, location-changed trials. Parallel to the keypress group, performance in the joystick group fully conformed to the predictions of the feature-mismatching hypothesis (Mayr et al., 2011; Park & Kanwisher, 1994) but did not show any evidence of inhibition.

Experiment 2

The aim of Experiment 2 was to further investigate the possible response-related inhibition in audition when distractor responses are activated and strive for the control of action. To this end, Experiment 2 used head movement responses toward sound locations for which, similar to unimanual joystick movements, spatial response and stimulus codes overlap, but which also exhibit a strong functional relationship to audiospatial processing.

Specifically, prior research strongly suggests that head movements represent ecologically valid motor responses to sounds. A recent review of psycho-acoustical, physiological, and experimental data supports the notion that processing along the auditory dorsal "where" pathway primarily serves to guide visual orientation by means of head movements to locations of interest (Arnott & Alain, 2011; see also Kubovy & Van Valkenburg, 2001, for a similar conclusion). This is further corroborated by research showing that changes in head position toward auditory events can be observed even in newborn children as part of a presumably innate orientation reflex (e.g., Clifton, 1992; Pumphrey, 1950; Sokolov, Worters, & Clarke, 1963). In the same vein, Perrott, Saberi, Brown, and Strybel (1990) proposed that the main function of sound localization is to generate head movements toward the sound source to enable foveal processing of sound-emitting objects (see also Hafter & De Maio, 1975; Heffner & Heffner, 1992). In support of this idea, Perrott et al. found improved search performance when visual targets were accompanied by spatially corresponding sounds, as compared with noncorresponding sounds. Moreover, in a study by Corneil and Munoz (1996), participants performed conjoint head and eye movements to the location of a visual or auditory target stimulus presented on the left or right of fixation while ignoring an irrelevant visual or auditory stimulus, presented either on the left or the right side. Most important to the present experiment, irrelevant sounds triggered initial head and eye movements toward their locations. This tendency was most prominent when target and distractor stimuli were presented in close temporal proximity. This finding strongly supports the notion that head movement responses are directly activated by distractor sounds.

On the basis of this rich body of empirical evidence documenting direct activation of head movement responses to auditory stimuli, this response mode seemed to be particularly suited to further test the response inhibition account of auditory spatial negative priming, which was the aim of Experiment 2B. However, before measuring the potential aftereffects of response inhibition in Experiment 2B, we conducted Experiment 2A, which was parallel to Experiment 2B with respect to the general task and the spatial arrangement of speakers used. In Experiment 2A, we tested whether irrelevant sounds presented in the experimental setting used in Experiment 2B would, in fact, influence head movement responses.

Experiment 2A

In Experiment 2A, latency and accuracy measures of head movement responses to target sound locations were compared between trials with and without a simultaneously played distractor sound. Most important for the present purposes, the influence of distractors on spatial characteristics of target-directed head movements were also examined. The rationale underlying this analysis was as follows: If simultaneously played distractor sounds modify spatial movement parameters of target-directed head responses, this would strongly imply that irrelevant spatial sounds indeed activate their corresponding responses in the present experimental setting. In other words, this would indicate that auditory distractor processing does not stop at an early, possibly perceptual level but continues to a premotor or even motor stage where the interference with the target-directed movement occurs.

Method

Participants

One left-handed and 21 right-handed students (8 males) participated (age range: 23–37 years; M=25). They were tested individually and were paid or received course credit.

Materials

The materials of Experiment 2A were identical to those of Experiment 1, with the following exceptions. The triangle sound was replaced by a clarinet sound to improve the discriminability of the instrumental stimuli. Participants sat 100 cm away from the monitor. The distance between the participant and the speakers was 87 cm. The distance between adjacent speakers was 30°, so that the speakers were located at 30° (L2 and L3) and 60° (L1 and L4) to the left and right of the sagittal head–computer-display axis (see Fig. 1a). The height of speakers L1 and L4 was 103 cm. The height of speakers L2 and L3 was 153 cm. As a consequence, the outer speakers L1 and L4 were located below the eye level of a seated participant, while the inner speakers L2 and L3 were located above the eye level. The change in speaker layout resulted in more easily distinguishable head movement angles to the four speakers, as extensive pretesting had revealed.

Each trial comprised the presentation of a visually precued target sound. On half of the trials, a simultaneous distractor sound was presented from a different speaker (*distractor present*). On the other half of the trials, the target sound occurred alone (*distractor absent*).

Participants were instructed to turn their head toward the speaker emitting the target sound while ignoring the distractor sound. The speaker arrangement required participants to shift their head downward to the left or right side to respond to the outer speaker locations L1 and L4, respectively. The speaker positions L2 and L3 demanded an upward turn of the head slightly directed to the left and right, respectively. To record the head movements, an infrared camera (SmartNav, NaturalPoint Inc., Corvallis, OR) was mounted on top of the screen at a height of 128 cm. A self-adhesive, infrared-reflecting dot was placed on the participants' forehead just above the nasion. The camera tracked the vertical and horizontal positions of the reflective dot with a sampling frequency of 125 Hz. The position of the dot within the cameras' field of view was translated into x–y screen coordinates of the invisible mouse cursor (similar to the translation of joystick responses in Experiment 1). A change in head orientation resulted in a spatially corresponding change of the mouse cursor. Initially, participants were asked to orient their head toward the screen and to focus on a fixation cross at the center of the screen. The resulting head posture was defined as the starting position for all subsequent head movements, and the mouse cursor was set to the central coordinate of the screen. As a visual aid to reestablish the starting head position at the beginning of each presentation, the padded end of a pole (which was mounted on a microphone stand) was individually adjusted so that it provided a point of reference for the participants' chin. The arrangement did not restrict participants' mobility of the head. A response was registered when a head movement displaced the mouse cursor by more than 250 pixels in any direction away from the central coordinate of the screen. The x-, y-coordinates at which the mouse cursor exceeded the 250-pixel radius were used to determine the direction in which the head had been turned. To this end, four equally sized segments (70°) of the virtual circle with the central coordinate as the midpoint were defined as response segments. Each of the segments was assigned to one of the four speakers; the segment-to-speaker mapping was spatially compatible (see Fig. 1b). Head movements exceeding the 250-pixel radius within these segments were counted as valid responses toward the appropriate speakers. A segment of 80° was not assigned to a speaker because head movements ending in this segment were spatially incompatible with responses to any of the four speakers. Responses within this segment occurred very infrequently (<0.001 % of all responses) and were excluded from the statistical analysis. Parallel to Experiment 1, the response parameters in Experiment 2A—250-pixel radius response criterion, response segment size, and arrangement—were the result of extensive testing aimed at optimizing the distinctiveness of the four responses while preserving the naturalness of the head movements. Participants were instructed to turn their head toward a target speaker such that the tip of their nose pointed to a blue tape patch attached at the top left (right) corner of the speakers positioned to the left (right) of the computer screen. This instruction was to encourage participants to perform head movements instead of mere eye movements toward the sound sources. The head position was assessed at visual cue onset in each presentation. Initial head orientations were considered invalid if they corresponded to a displacement of the cursor of more than 200 pixels away from the central coordinate. Trials with invalid starting positions occurred very rarely (0.003 % of all presentations) and were immediately repeated until the position criterion was met. These repeated trials were excluded from the statistical analysis.

To generate distractor-present trials, target and distractor locations were chosen from the four speaker locations, with the restriction that the two sounds could not be emitted from the same speaker. This resulted in 12 unique trials. Next, sound identity was added. All target location by sound identity (guitar, drum, clarinet, harmonica) combinations were instantiated, generating 48 trials in total. The identity of the distractor sound was randomly chosen, with the restriction that it had to differ from the target sound. The procedure was repeated once to generate a total of 96 trials. The 96 distractor-absent trials were parallel to the distractor-present trials, except that the distractor was omitted. The resulting 192 trials were presented in random order. Prior to the experiment, a maximum of 24 training trials (12 distractor-present trials, 12 distractor-absent trials) were randomly presented. Participants proceeded to the experimental phase if they had responded correctly to at least 75 % of the past 15 trials.

Head movement angles were calculated in four steps. First, a straight line was established between the coordinate that exceeded the 250-pixel criterion and the central coordinate on the screen. In a second step, the angle for this response line was determined with reference to a full circle. A response angle of 0° corresponded to a head movement directed to the left, while a head movement to the right resulted in a movement angle of 180°.

An average response angle was calculated for each of the four target locations in the distractor-absent condition and for each of the 12 combinations of target and distractor locations in the distractor-present condition. Then, for each target location, the difference between the average response angle in the distractor-absent condition and the average response angle in each of the three corresponding target–distractor combinations in the distractor-present condition were computed (e.g., the average response angle in the distractor–absent condition with the target sound at location L1 was compared with the three distractor–present combinations that contained the target at L1 and the distractor at L2, L3, or L4). To preserve directional information, the resulting differences were recoded to have a negative sign when the response angle in the distractor–present condition indicated a head movement toward the location of the irrelevant sound (as compared with the appropriate distractor–absent condition). Conversely, the resulting differences were recoded to have a positive sign when the response angle in the distractor–present condition indicated a head movement away from the location of the irrelevant sound. Finally, the average response angle difference between the distractor–absent and distractor–present conditions was calculated.

Procedure

At the beginning of each trial, a fixation cross was replaced by a picture cue that indicated the to-be-attended instrument. After 500 ms, the corresponding sound was presented from one of the four speakers and was either accompanied by another sound at a different location or presented alone. The visual cue remained on the screen until a head movement response was made or an interval of 3,000 ms had been exceeded. Successive trials were separated by a 1,000-ms interval during which the fixation cross was visible.

Design

The experiment comprised distractor presence (present vs. absent) as a within-subjects factor. The primary dependent variable was the average response angle of the head movements, but average reaction times and error rates were also analyzed.

Results

The results confirmed that the presence of a distractor sound impaired performance (see Fig. 3), as indicated by reliably longer response times and higher error rates in the distractor-present condition, as compared with the distractor-absent condition, $t(21) = -16.118$, $p < .001$,

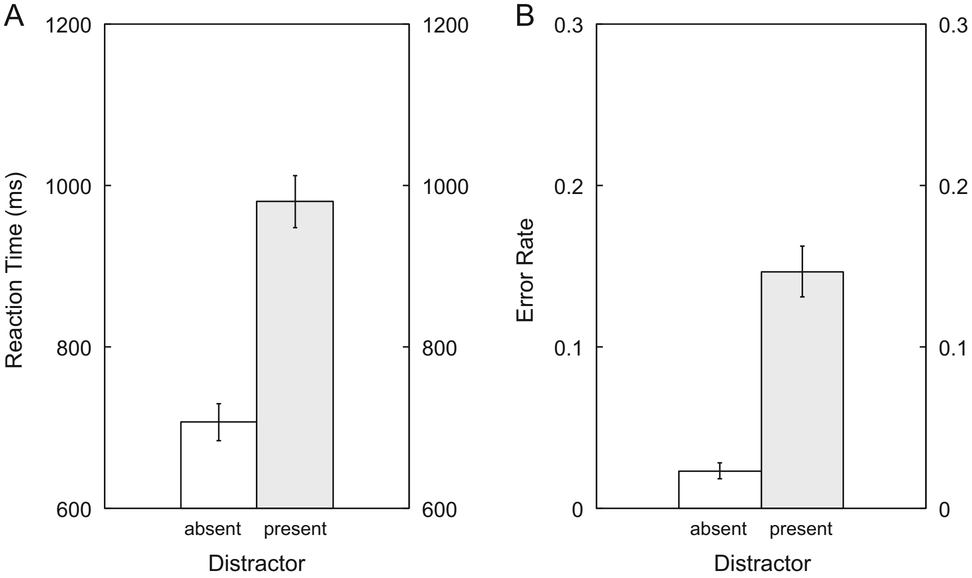

Fig. 3 Mean reaction times (**a**) and error rates (**b**) for head movement responses as a function of distractor presence (absent vs. present) in Experiment 2A. The error bars depict the standard errors of the means

d_z=3.436, and $t(21) = -9.272$, $p<.001$, d_z=1.977, respectively. Most important, a *t*-test confirmed that the response angles of the head movements differed between the distractor-present and distractor-absent conditions, $t(21)$=4.143, $p<.001$, d_z=0.883. Specifically, the response angles in the distractor-present condition were biased in the direction away from the distractor, indicating that the head movements counteracted and, in doing so, overcompensated the activated response toward the distractor sound location.

Discussion

Experiment 2A shows that spatially presented distractor sounds increase latency and reduce accuracy of head movement responses. Most important, the analysis of the response angles revealed that simultaneously played distractor sounds systematically influenced the spatial characteristics of the head movements toward the target sounds. The finding is well in line with the notion not only that audiospatial distractors interfere with target processing at a perceptual or conceptual level, but also that the responses toward distractor sounds in the present experimental setting are actually represented in the motor system.

The head movements to the target locations veered away from the location of the simultaneously presented distractor. Following action-based models of selective attention, a systematic movement deviation away from the distractor is typically interpreted as evidence for the inhibition of distractor-related response codes (e.g., Meegan & Tipper, 1998; Neyedli & Welsh, 2012; Tipper, Lortie, & Baylis, 1992; Welsh & Elliott, 2004; Welsh, Elliott, & Weeks, 1999; Welsh, Neyedli, & Tremblay, 2013). In essence, the models comprise the assumption that responses to target and nontarget stimuli are initially processed in parallel, competing for the control of action. Although target and distractor responses are individually encoded in terms of their respective movement directions, they can share spatial response codes. To illustrate, when a target stimulus activates a response toward a central-left location and a distractor activates a response directed straight to the left, both response codes share the spatial “left” feature. When the irrelevant response code (“left”) is subsequently inhibited to permit goal-directed behavior, the inhibitory mechanisms will also reduce the “left” component in the response code of the target response. As a result, the response toward the target location in the present example will consist of a more rightward movement and, thus, will veer away from the distractor location (see Houghton & Tipper, 1994, 1999, for a detailed description of the mechanisms and their presumed neural underpinnings). In sum, the present findings strongly suggest that responses to nontargets were activated and immediately inhibited, resulting in a distractor-evading head movement.

Experiment 2B

As was outlined above, the results of multiple studies, including those of Experiment 2A, highlight the relationship between audiospatial processing and head movement responses and suggest that irrelevant sounds directly activate head movement responses (e.g., Corneil & Munoz, 1996). Head movements thus seem to be an appropriate response modality to further test the response inhibition account of auditory spatial negative priming in Experiment 2B.

Method

Participants

Data of 76 participants were collected, 38 in each response mode group, but data from 1 participant in each group had to be excluded due to excessive error rates (>.50) in at least one experimental condition. In the final sample, 37 participants (27 females) ranging in age from 19 to 39 years (M=24) performed keypress responses, and 37 (24 females) ranging in age from 19 to 38 years (M=24) performed head movement responses. Three participants in each response group were left-handed. Participants were tested individually and either were paid or received course credit.

Materials and procedure

The materials and the procedure were identical to those of Experiment 1, with the following exceptions. As in Experiment 2A, the triangle sound was replaced by a recording of a clarinet. Participants responded to the location of the target sound either by manually pressing a corresponding response key or by turning their head toward the speaker that emitted the to-be-attended instrument. Head movement responses were measured by the method established in Experiment 2A. The blue tape patches that marked the response goal in the head movement group were also present for participants in the keypress group but were not referred to in the instructions. The two training phases corresponded to those of Experiment 1. The timing of a trial was identical to that of Experiment 1, except that the prime–probe response stimulus interval was extended to 1,200 ms to grant participants more time to resume their starting head posture prior to the probe presentation.

Head movements that ended in a response segment that was not assigned to a speaker location (see Fig. 1b) occurred infrequently (0.9 % of all responses) and were excluded from the statistical analysis. Trials with invalid starting positions also occurred rarely (1.3 % of all presentations) and were immediately repeated until the position criterion was met. These repeated trials were excluded from the statistical analysis.

Design

The design was identical to that of Experiment 1. A power analysis showed that given $\alpha=\beta=.05$ and a sample size of $N=37$, effects of size $d_z=0.50$ (medium effects in terms of Cohen, 1988) between sound-changed, location-changed control trials and each remaining trial type could be detected with a power of $1-\beta=.91$ for each response mode.

Results

Probe responses were evaluated only when they followed a correct prime response so that 14.6 % and 9.9 % of the hypothesis-relevant trials in the ignored repetition subdesign did not enter the statistical analysis for the head movement and keypress groups, respectively. The test statistics are reported in Table 2. Mean response times and error rates of head movement and keypress responses in the ignored repetition subdesign are shown in Fig. 4.

For head movement responses, responding was reliably prolonged on trials with a prime-to-probe mismatch (i.e., on sound-changed, location-repeated and sound-repeated, location-changed trials), as compared with control trials. Response times did not differ between sound-repeated, location-repeated and control trials. The error rates were compatible with the response time pattern, since accuracy was reliably lower on sound-changed, location-repeated trials, as compared with control trials. Error rates were descriptively higher on sound-repeated, location-changed trials than on control trials, but the statistical test of this difference fell short of significance (due to the Bonferroni–Holm method).

For keypress responses, trials exhibiting a mismatch between prime and probe presentations were associated with longer response times, as compared with control trials. In contrast, responding to the probe target was not prolonged if the sound identity of the probe target matched the identity and the location of the former prime distractor in sound-repeated, location-repeated trials. The error rates did not differ among conditions and, thus, do not complicate the interpretation of the latency data. As in Experiment 1, the pattern of performance did not differ between the response modes as indicated by the absence of any interactions involving the response mode factor, all $Fs(1, 72)\leq 2.947$, $p\geq .090$, $\eta^2\leq .039$.

Discussion

The results of Experiment 2B are clear: Responding with keypresses, as well as with head movements, was strongly affected by the occurrence of feature mismatches, as evidenced by impaired performance on sound-changed, location-repeated as well as sound-repeated, location-changed trials. If distractor-assigned response inhibition affected subsequent responding, performance on sound-repeated, location-repeated trials should have been impaired. But that was not the case. Performance did not

Table 2 Statistical results and critical alpha levels for each comparison of Experiment 2B

Experiment 2B (N=74, $n_{\text{Head Movement}}=n_{\text{Keypress}}=37$)

		Head Movement Responses							
		Reaction Times (ms)				Error Rate			
Effect (Trial Type – Control)	*df*	*t*	*p*	α_{critial}	d_z	*t*	*p*	α_{critial}	d_z
Sound-changed, location-repeated	36	**3.095**	**.002**	**.017**	**0.509**	**2.652**	**.006**	**.017**	**0.436**
Sound-repeated, location-changed	36	**2.187**	**.018**	**.025**	**0.360**	1.719	.047	.025	0.283
Sound-repeated, location-repeated	36	0.285	.389	.050	0.047	−0.175	.431	.050	0.029
		Keypress Responses							
		Reaction Times (ms)				Error Rate			
Effect (Trial Type – Control)	*df*	*t*	*p*	α_{critial}	d_z	*t*	*p*	α_{critial}	d_z
Sound-changed, location-repeated	36	**3.157**	**.002**	**.017**	**0.519**	0.895	.189	.017	0.147
Sound-repeated, location-changed	36	**2.331**	**.013**	**.025**	**0.383**	0.223	.413	.050	0.037
Sound-repeated, location-repeated	36	−0.046	.482	.050	0.008	−0.571	.286	.025	0.094

Note. Test statistics of the paired-sample *t*-tests (*t*, *p*, and α_{critical}) and effect sizes (d_z) for probe reaction times and error rates for head movement (upper panel) and keypress (lower panel) responses in Experiment 2B. Sound-changed, location-changed trials served as control for all comparisons. Significant effects (with respect to the critical α-level determined by the Bonferroni–Holm correction) are printed in bold.

differ from control trials when prime distractor and probe target were identical with respect to sound identity and location. In sum, the pattern of results in both response groups is compatible with the predictions of the feature-mismatching hypothesis, whereas inhibition does not seem to play a role.

General discussion

Two spatial negative priming experiments were conducted to specify the mechanisms that underlie correct responding in auditory environments that contain relevant and irrelevant sound sources. In Experiment 1, participants indicated the location of a target sound either by pressing an assigned response key or by moving a joystick toward the target sound source, while keypress and head movements were required in Experiment 2B. Unimanual spatially directed joystick responses and head movements were used to ensure distractor-related response activation and, thus, to maximize the chances to find evidence of response-related inhibition (Burle et al., 2002; Ridderinkhof, 2002; Schlaghecken & Eimer, 2002). Experiment 2A was designed to provide independent evidence of response activation for head movements toward nontarget sound sources.

The results for the spatial negative priming tasks can be summarized as follows: Independent of whether the required response was a manual keypress, a joystick movement, or a head turn toward the target location, performance in Experiment 1 and 2B was compatible with the predictions of the feature-mismatching hypothesis (Park & Kanwisher, 1994). Moreover, no aftereffects of distractor response inhibition were found in the subsequent trials of any of the response modes employed. The absence of inhibitory aftereffects is most remarkable for the spatial negative priming task with head movement responses (Experiment 2B), given that Experiment 2A strongly indicates that head movements toward irrelevant sound sources are activated and immediately inhibited in the present experimental setting.

Specifically, the results of Experiment 2A confirm the assumption that distractor-assigned responses are actually activated when a strong perceptuo-motor coupling between stimulus events and response type is provided (as in the case of head movement responses to sound sources). This suggests that distractor response processing up to the activation of corresponding responses is not limited to vision but also occurs in the auditory modality (Buetti & Kerzel, 2008; Corneil & Munoz, 1996; Leuthold & Schröter, 2006). In the same vein, we further conclude that the suppression of distractor responses—as a mechanisms to prevent false responding—operates in both modalities. Together, these findings suggest that distractor processing does not fundamentally differ between the visual and auditory modalities.

It is important to note that head movement responses in Experiment 2A veered *away* from the distractor location, while spatially directed responses were drawn *toward* nontarget locations in prior studies of auditory distractor processing (e.g., Buetti & Kerzel, 2008; Corneil & Munoz, 1996). To reiterate, movement deviations toward the nontarget location are taken as evidence that distractor-related responses are activated, while deviations away from the distractor location are interpreted as reflecting the inhibition of distractor responses (e.g., Tipper et al., 1992; Welsh & Elliott, 2004). It follows that Experiment 2A provides evidence of the inhibition of distractor responses on the ongoing trial, which implies

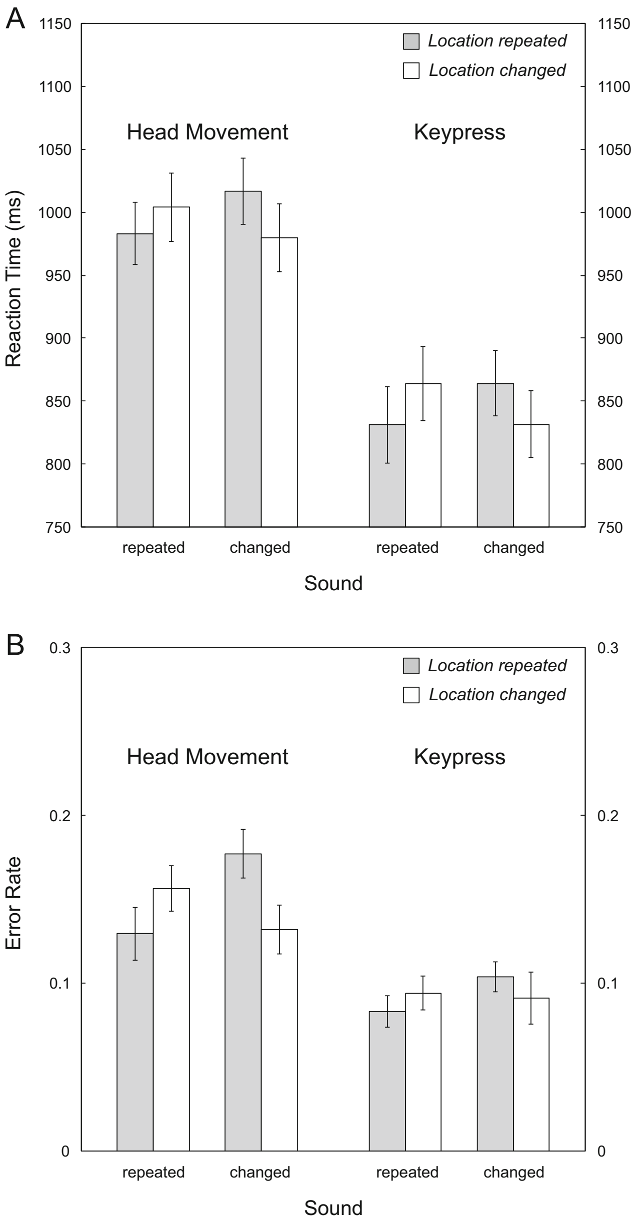

Fig. 4 Mean reaction times (**a**) and error rates (**b**) for head movement and keypress responses as a function of location repetition (repeated vs. changed) and sound repetition (repeated vs. changed) in the ignored repetition subdesign of Experiment 2B. The error bars depict the standard errors of the means

that the distractor responses must have been activated to a degree that interferes with correct responding, because without sufficient initial activation, an inhibitory mechanism would not have been triggered (Burle et al., 2002; Ridderinkhof, 2002; Schlaghecken & Eimer, 2002; Wyatt & Machado, 2013). Given this, it is easy to reconcile the present findings in the auditory modality with previous findings in the visual modality without assuming fundamental differences in target and distractor processing in the two modalities. Specifically, prior studies analyzed response directions right after the movements were initiated. In the present Experiment 2A, in contrast, the direction of a response in terms of the response movement angle was determined relatively late (when the mouse cursor was displaced by 250 pixels from the central coordinate of the screen). It has been argued that initial movement components primarily reflect the simultaneous activation of target and distractor responses (e.g., Welsh & Elliott, 2004). As a result, initial movement components comprise features of target and distractor responses and, consequentially, veer toward the distractor location (Buetti & Kerzel, 2008; Corneil & Munoz, 1996). In contrast, later movement components (as in the present experiments) are already affected by the subsequent inhibitory mechanism that suppresses the distractor response, which is why these later head movements veered away from the nontarget sound source in Experiment 2A.

Although previous research, as well as the results of Experiment 2A, suggests that movements toward auditory distractor sounds are inhibited, no spatial negative priming effect was obtained in Experiments 1 and 2B, which is strikingly different from related findings in the visual modality (e.g., Buckolz, Edgar, et al., 2012; Guy & Buckolz, 2007). The absence of an aftereffect attributed to response inhibition (i.e., the spatial negative priming effect) in the present tasks indicates different time courses of inhibition in visual and auditory processing. Although responses to nontarget sound sources seem to be activated and inhibited during individual presentations (as indicated by Experiment 2A), their execution on the subsequent probe trial is not delayed. Presumably, the inhibitory status of a response has dissipated after 1,000 and 1,200 ms in audition (response-to-stimulus-interval in Experiments 1 and 2B, respectively). In contrast, measurable aftereffects of response inhibition in the visual modality still occurred after intervals of up to 10 s between the prime response and the corresponding probe presentation (e.g., Buckolz, Avramidis, & Fitzgeorge, 2008). Therefore, the present results suggest that the inhibitory status of the distractor response is more persistent in vision than in audition.

The different time courses of the inhibitory aftereffects in visual and auditory spatial negative priming are most readily explained by referring to the general framework of response-related inhibition outlined in the introduction. To reiterate, prior evidence suggests that the amount of distractor inhibition devoted to a nontarget event is positively related to its initial strength of activation (e.g., Grison & Strayer, 2001; Houghton et al., 1996; Schuch et al., 2010; Wyatt & Machado, 2013). With respect to our present findings, it is conceivable that, although distractor-assigned head movement responses were sufficiently activated to trigger a response inhibition mechanism (as indicated by the results of Experiment 2A), the strength of this activation–inhibition sequence for nontarget responses in audition might still be lower, as compared with related processing in the visual modality. This seems plausible because the link between spatial stimulus and response processing is stronger and more direct in vision than in audition (e.g., Barfield et al., 1997; Wascher et al., 2001; Wickens et al., 1983; Wickens et al., 1984). As a consequence, the somewhat lower amount of distractor response inhibition established in auditory prime processing might dissipate sooner over the course of the response–stimulus interval and is presumably fully eliminated after 1,000 and 1,200 ms, respectively. Alternatively, it might be the case that inhibitory response information attached to the prime distractor is stored in an episodic format that can be retrieved by feature repetitions at the time of the probe presentation. However, due to the presumably weaker link between audiospatial processing and static manual responding, distractor-related response information might be only encoded to a lesser extent as part of the prime episode in auditory, as compared with visual, processing. Any response-related distractor information might therefore decay sooner over time in auditory spatial negative priming, thereby only affecting immediate responding.

Taken together, our findings support the notion that the activation and subsequent inhibition of distractor-assigned responses are common mechanisms in visual and auditory processing, whereas these modalities differ with respect to the strength of these processes, which, in turn, affects the persistence of the spatial negative priming effect. However, since the present results are the first to provide evidence for response-related inhibition in auditory spatial negative priming, determining the exact nature of the process clearly requires further experimental investigation.

Turning to the clear-cut evidence in favor of the feature-mismatching hypothesis (Park & Kanwisher, 1994), the results in all four experimental groups of Experiments 1 and 2B underscore the significance of object-file formation in audition. The fact that feature-mismatching effects were found for sounds that used to be distractor sounds in the previous prime presentation suggests that (identity and location) features of irrelevant sound events are also bound into object files. This can be taken as further evidence that correct responding in auditory spatial negative priming tasks is not only achieved by processing the identity and the location of target sounds (as precued by the selection criterion). If this were a valid assumption, then there should not have been evidence for the detection of prime-distractor-to-probe-target feature mismatches. In order to disentangle relevant and irrelevant aspects in an auditory scenario, concurrent target and distractor events seem to be integrated into separate object files prior to selection. Relevant object files, as defined by task instructions, are subsequently selected.

In conclusion, the present study suggests that distractor processing in audition also entails the inhibition of distractor-assigned responses, which we assume to have fully dissipated after 1,000 ms. Moreover, all findings in the present study unequivocally suggest that probe performance in auditory spatial negative priming is solely determined by the occurrence of feature-mismatching effects. This strongly indicates that processing in auditory spatial negative priming entails the integration of location and sound identity features of irrelevant sounds into object files. This, in turn, fits rather nicely with experimental findings in tasks outside the spatial negative priming paradigm (Dyson & Ishfaq, 2008; Hall, Pastore, Acker, & Huang, 2000; Maybery et al., 2009; Mondor, Zatorre, & Terrio, 1998; Parmentier, Maybery, & Elsley, 2010; Zmigrod & Hommel, 2009, 2010).

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Eidesstattliche Versicherung

Ich versichere an Eides Statt, dass die Dissertation mit dem Titel „Mechanisms of selection in auditory localization tasks: Evidence from the spatial negative priming effect“ von mir selbstständig und ohne unzulässig fremde Hilfe unter Beachtung der Grundsätze zur Sicherung guter wissenschaftlicher Praxis an der Heinrich-Heine-Universität Düsseldorf erstellt worden ist. Die Dissertation wurde in der vorgelegten oder in ähnlicher Form noch bei keiner anderen Institution eingereicht. Ich habe bisher keine erfolglosen Promotionsversuche unternommen.

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