Université de Montréal

Suivez le guide : études comportementales et électrophysiologiques du rôle des contrôles attentionnels descendants dans le déploiement de l'attention visuospatiale

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RÉSUMÉ

La capture contingente de l'attention est un phénomène dans lequel les mécanismes d'orientation endogène et exogène de l'attention interagissent, de sorte qu'une propriété qui est pertinente à la tâche en cours, et donc qui fait l'objet de contrôles attentionnels descendants, endogènes, capture l'attention de façon involontaire, exogène, vers sa position spatiale.

Dans cette thèse, trois aspects de ce phénomène ont été étudiés. Premièrement, en explorant le décours temporel de la capture contingente de l'attention et la réponse électrophysiologique à des distracteurs capturant ainsi l'attention, il a été établi que le déficit comportemental symptomatique de cette forme de capture était lié à un déploiement de l'attention visuospatiale vers la position du distracteur, et que ce traitement spatialement sélectif pouvait être modulé par le partage d'autres propriétés entre le distracteur et la cible.

Deuxièmement, l'utilisation des potentiels liés aux événements a permis de dissocier l'hypothèse de capture contingente de l'attention et l'hypothèse de capture pure de l'attention. Selon cette interprétation, un stimulus ne peut capturer l'attention aux stades préattentifs de traitement que s'il présente le plus fort signal ascendant parmi tous les stimuli présents. Les contrôles attentionnels descendants ne serviraient donc qu'à désengager l'attention d'un tel stimulus. Les résultats présentés ici vont à l'encontre d'une telle interprétation, puisqu'un déploiement de l'attention visuospatiale, indexé par la présence d'une N2pc, n'a été observé que lorsqu'un distracteur périphérique possédait une caractéristique pertinente à la tâche en cours, même lorsque ses propriétés de bas niveau n'étaient pas plus saillantes que celles des autres items présents.

Finalement, en utilisant un paradigme où la cible était définie en fonction de son appartenance à une catégorie alphanumérique, il a été démontré que des contrôles attentionnels en faveur d'un attribut conceptuel pouvaient guider l'attention visuospatiale de façon involontaire, rejetant une nouvelle fois l'hypothèse de la capture pure de l'attention.

Mots clés : neurosciences cognitives, attention visuospatiale, capture contingente de l'attention, mécanismes endogènes, mécanismes exogènes, propriété conceptuelle, catégorie alphanumérique, électrophysiologie, potentiels liés aux événements, N2pc.

ABSTRACT

Contingent involuntary orienting is a phenomenon in which endogenous and exogenous attentional mechanisms interact, such that an item captures attention only if it shares an attribute that is relevant for the task at hand. Hence, top-down attentional control settings are established endogenously in favour of the relevant attribute, but stimuli sharing this attribute draw attention to their location involuntarily.

The present thesis explores three aspects of this phenomenon. First, by studying the time course of this contingent capture effect, and by measuring event-related potentials (ERPs) to capturing distractors, it has been established that the performance deficits linked to contingent capture are in fact due to a deployment of visuospatial attention to the location of the distractor. Moreover, this spatially selective processing of the capturing distractor can be modulated if the distractor shares another target attribute, beside the target defining attribute.

The ERP technique also permitted the dissociation of the contingent involuntary orienting hypothesis and the pure capture with brief attentional dwell time hypothesis. According to the latter interpretation, only salient singletons have the ability to capture attention at preattentive stages of processing. Therefore, top-down attentional control settings serve only to disengage attention from the location of such singletons when they do not share target features. The present results argue against this interpretation, because a deployment of visuospatial attention, indexed by the presence of the N2pc, was observed only in response to peripheral distractors sharing the target-defining attribute, even when all items in the stimulus displays were equated in terms of bottom-up salience.

Lastly, when alphanumeric category was used to define the target, it was shown that top-down attentional control settings in favour of such conceptual attributes could be successfully implemented and used to guide visuospatial attention in an exogenous fashion, providing further evidence against the pure capture hypothesis.

Keywords: cognitive neuroscience, visuospatial attention, contingent capture, endogenous mechanisms, exogenous mechanisms, conceptual attribute, alphanumeric category, electrophysiology, event-related potentials, N2pc.

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EEG	Électroencéphalogramme / *Electroencephalogram*
EOG	*Electrooculogram*
ERP	*Event-related potentials*
fMRI	*Functional magnetic resonance imaging*
HEOG	*Horizontal electrooculogram*
IRMf	Imagerie par résonnance magnétique fonctionnelle
ms	milliseconde / *millisecond*
N2pc	N2 postérieure controlatérale / *N2 posterior contralateral*
PLE	Potentiels liés aux événements
PVSR	Présentation sérielle visuelle rapide
RSVP	*Rapid serial visual presentation*
SOA	*Stimulus onset asynchrony*
SPCN	*Sustained posterior contralateral negativity*
VEOG	*Vertical electrooculogram*

À Samika,

Toute petite chose,

C'est pourtant grâce à toi que j'ai trouvé

mon équilibre et ma voie dans cette aventure

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INTRODUCTION GÉNÉRALE

PRÉAMBULE

Imaginez un voyageur qui arrive dans une nouvelle ville et qui n'a qu'une semaine pour l'explorer. Impossible de tout voir, de tout visiter, et pourtant, il aimerait bien repartir de son voyage en ayant connu une expérience assez représentative de cette ville étrangère : sa culture, ses attractions, etc. Comment s'y prendra-t-il?

Notre système cognitif fait sans cesse face à la même problématique : à tout moment, il y a mille choses à percevoir et à analyser pour bien guider notre comportement, or il est impossible de les traiter toutes. Notre attention, telle un voyageur, parcourt notre univers visuel et détermine quelles informations seront explorées en profondeur par nos ressources cognitives, disponibles en quantité limitée, comme les jours de voyage.

Pour maximiser l'intérêt et la pertinence des endroits visités pendant son séjour à l'étranger, un voyageur pourrait planifier son voyage consciencieusement en consultant tous les guides touristiques, les pamphlets des musées, des restaurants, etc. Avec toutes ces informations recueillies, il pourrait alors établir un itinéraire incluant les principales destinations qui, jugerait-il, lui permettrait de connaître suffisamment la ville. Cependant, toute cette recherche lui prendrait beaucoup de temps et d'efforts, et, en bout de ligne, pourrait diminuer la quantité d'endroits qu'il aurait l'occasion de visiter.

De la même façon, nous pouvons guider notre attention de façon volontaire et contrôlée à travers une scène visuelle, mais il s'agit d'un processus qui requiert beaucoup de ressources cognitives en soi.

À l'opposé, le voyageur pourrait choisir d'aller se balader au hasard dans cette ville, s'arrêtant aux endroits qui captent son regard : les restaurants qui font le plus de publicité, les musées qui ont la devanture la plus criarde, les bâtiments les plus imposants. Même si elle requiert peu d'effort et maximise le temps passé à explorer la ville, cette approche a un inconvénient de taille : la pertinence des endroits visités pourrait être discutable. Par exemple, le voyageur se retrouverait probablement dans une franchise d'une chaîne internationale de restauration rapide plutôt que de découvrir un petit restaurant local…

Ainsi, notre attention peut être capturée par des éléments très saillants de notre environnement, par exemple, les gyrophares d'un véhicule d'urgence. Ceci peut être très utile pour faire face à des situations imprévues, mais toutes les informations importantes ne sont pas si saillantes.

Une troisième approche pour notre voyageur serait d'engager un guide, et de lui spécifier ses intérêts : veut-il s'initier à la gastronomie régionale? Découvrir l'architecture typique ou les œuvres d'art public? Visiter les hauts lieux de la culture locale? Il n'aurait alors qu'à suivre le guide, qui aurait déjà sélectionné une série d'endroits à visiter en fonction des ses demandes d'une part, et des attraits particuliers de la ville d'autre part.

Existe-t-il un tel guide pour aider notre attention à localiser l'information la plus pertinente pour nous à un moment bien précis? C'est ce que suggère l'hypothèse de la capture contingente de l'attention. Selon cette hypothèse, il serait possible d'établir, en fonction des demandes d'une tâche à accomplir, des contrôles attentionnels. Ces contrôles agiraient comme un guide, qui provoquerait l'orientation de l'attention visuospatiale vers les éléments pertinents d'une scène visuelle, toujours en fonction des demandes de la tâche, sans que cette orientation n'ait à être initiée de façon volontaire et contrôlée. Ainsi, un ensemble de stimuli pourrait être traité de façon plus efficace, tout en tenant compte des exigences particulières de chaque situation.

Dans ma thèse, je propose trois études qui permettent de mieux connaître ce guide attentionnel.

L'ATTENTION VISUOSPATIALE

Selon Desimone et Duncan (1995), le traitement de l'information présente dans le champ visuel est caractérisé par deux phénomènes. Premièrement, l'information étant disponible en quantité virtuellement infinie, elle se butte à la capacité limitée du système cognitif, incapable de la traiter dans son entièreté. Ainsi, il y a compétition entre diverses portions du champ visuel, ou encore divers objets qui s'y trouvent, pour accéder aux ressources cognitives. Deuxièmement, pour résoudre ce conflit tout en maximisant la pertinence de l'information qui sera effectivement traitée, une sélection s'opère au sein du système cognitif. Cette sélection peut se faire par voie ascendante, basée sur les stimuli, ou encore par voie descendante, basée sur les objectifs de l'observateur. Dans la sélection ascendante, ce sont les propriétés physiques des stimuli qui sont déterminantes. L'attention est alors dirigée automatiquement vers un item qui apparaît subitement dans le champ visuel, ou encore vers un singleton, c'est-à-dire un item qui diffère de son entourage par une caractéristique qui lui est propre, comme la couleur ou l'orientation. À l'inverse, dans la sélection descendante, l'observateur déploie volontairement son attention vers des positions où il juge qu'une information importante pourrait être présente. Ainsi, ce ne sont pas les propriétés physiques des objets qui guident l'attention, sans contrôle de la part de l'observateur, mais bien les buts de ce dernier, en fonction des tâches qu'il cherche à accomplir.

LES MÉCANISMES ENDOGÈNE ET EXOGÈNE DE L'ORIENTATION DE L'ATTENTION VISUOSPATIALE

Les deux modes de sélection, ascendant et descendant, correspondent donc à deux mécanismes de déploiement de l'attention visuospatiale : involontaire (ou exogène) et volontaire (ou endogène). Ces deux mécanismes sont bien représentés dans le paradigme d'indiçage spatial (Posner, 1980). Dans ce paradigme, l'observateur doit effectuer une tâche de détection ou de discrimination portant sur un stimulus (la cible) présenté en périphérie du champ visuel. Préalablement, un indice quant à la position spatiale possible de la cible est présenté. Cet indice peut-être valide, c'est-à-dire qu'il indique correctement la position de la cible, ou invalide, il guide alors l'observateur vers une position autre que celle où la cible sera présentée. Les résultats typiques dans une tâche d'indiçage spatial démontrent un effet de validité, c'est-à-dire que la performance à la tâche reliée à la cible, mesurée soit par les temps de réponse ou le taux de réponses correctes, est meilleure lorsque la cible a été indicée de façon valide que lorsque celle-ci suit un indice invalide.

Le mécanisme qui guide le déploiement de l'attention visuospatiale vers la position indiquée par l'indice, soit volontaire ou involontaire, est réputé dépendre du type d'indice utilisé. Les indices périphériques, comme leur nom l'indique, sont présentés en périphérie du champ visuel et peuvent consister en un changement de luminance, en l'apparition soudaine d'un stimulus, ou en un mouvement d'un stimulus existant, pour ne nommer que quelques exemples. Ils sont associés à une capture exogène de l'attention. Les indices centraux, quant à eux, sont présentés au point de fixation et sont porteurs d'une valeur symbolique, par exemple, une flèche, qui guide l'observateur vers une position du champ visuel. Ils contribueraient à une allocation volontaire et contrôlée, donc endogène, de l'attention (Müller & Rabbitt, 1989; Posner & Cohen, 1984). Toutefois, l'aspect volontaire du déploiement attentionnel est davantage lié à la valeur informative de l'indice, périphérique ou central (Prinzmetal, McCool, & Park, 2005). Donc, même des indices périphériques, s'ils sont prédictifs de la position de la cible (i.e., s'ils indiquent correctement la position de la cible plus souvent qu'au hasard), peuvent engendrer un déploiement volontaire de l'attention.

Le paradigme d'indiçage spatial a également permis de caractériser les modes d'allocation endogène et exogène de l'attention. Tout d'abord, il a été observé que ces deux processus opéraient selon des mécanismes et des décours temporels distincts. L'orientation exogène de l'attention entraîne une facilitation du traitement des stimuli présentés dans la position indicée, et une inhibition du traitement des stimuli apparaissant aux autres positions. Ces mécanismes sont mis en place rapidement, soit moins de 175 ms après la présentation de l'indice (Müller & Rabbitt, 1989). À des délais plus longs, la facilitation et l'inhibition seront maintenues à un niveau moindre si l'indice possède une valeur prédictive. Par contre, en l'absence d'incitatif à orienter volontairement son attention vers la position indicée, le phénomène d'inhibition de retour sera observé, c'est-à-dire que la performance à un stimulus validement indicé sera moins bonne que s'il est présenté dans une position qui n'a pas été indicée (Posner & Cohen, 1984). Pour ce qui est de l'attention volontaire, seule la facilitation de la position indicée est observée (Posner & Cohen, 1984). Elle s'établit de façon plus graduelle et est maintenue de façon prolongée (Müller & Rabbitt, 1989; Posner & Cohen, 1984).

Corrélats neurophysiologiques des mécanismes d'orientation endogène et exogène

Des études employant des paradigmes d'indiçage spatial ainsi que l'imagerie par résonnance magnétique fonctionnelle (IRMf) ont dissocié deux réseaux responsables des mécanismes d'orientation endogène et exogène dans le cerveau. Le premier, dorsal fronto-pariétal, recrute principalement le sulcus intrapariétal et les champs oculaires frontaux, et serait avant tout impliqué dans le contrôle endogène de l'attention, agissant par le biais de connexions descendantes en fonction des contrôles attentionnels (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Corbetta & Shulman, 2002; Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005). Le second, ventral fronto-pariétal, est centré autour de la jonction temporo-pariétale et plutôt latéralisé dans l'hémisphère droit. Il servirait à diriger l'attention en fonction des propriétés physiques des stimuli qui signalent une certaine pertinence pour le choix des comportements à effectuer. Il est notamment activé lorsque l'attention doit être redirigée vers la position d'une cible qui a été incorrectement indicée (Arrington, Carr, Mayer, & Rao, 2000; Corbetta, Kincade, & Shulman, 2002; Corbetta & Shulman, 2002; Indovina & Macaluso, 2007; Kincade et al., 2005).

INFLUENCE DES MÉCANISMES ENDOGÈNES SUR LE DÉPLOIEMENT EXOGÈNE DE L'ATTENTION

L'hypothèse de la capture contingente de l'attention

Malgré que les modes attentionnels volontaire et involontaire semblent constituer deux systèmes distincts, il existe des interactions entre les deux. Nommément, l'hypothèse de la capture contingente de l'attention (Folk, Remington, & Johnston, 1992, 1993) stipule que l'attention ne peut être capturée que par un stimulus qui présente une propriété essentielle à l'accomplissement de la tâche en cours, et en faveur de laquelle l'observateur doit donc adopter des contrôles attentionnels descendants. Ainsi, un stimulus provoquerait un déploiement de l'attention vers sa position non pas à cause de la saillance de ses propriétés physiques, mais bien à cause de la correspondance entre celles-ci et les contrôles attentionnels descendants de l'observateur. La capture contingente de l'attention procèderait donc de mécanismes endogènes, soit l'établissement des contrôles attentionnels, et exogènes, puisqu'une fois ces contrôles mis en place, les stimuli possédant la propriété critique captureraient l'attention de façon involontaire.

Ce phénomène a été observé par Folk et ses collègues (1992) dans le cadre d'un paradigme d'indiçage spatial modifié, illustré dans la Figure 1. Pour certains participants, la cible était un stimulus qui apparaissait de façon soudaine dans l'une des quatre positions périphériques indiquées par des cases à l'écran. Pour un second groupe de participants, des items étaient présents dans les quatre positions, mais l'un d'eux, la cible, possédait une couleur unique, alors que les trois autres étaient de couleur uniforme. Deux types d'indices étaient également utilisés : des indices à apparition soudaine et des indices de couleur unique. Un indice à apparition soudaine consistait en la présentation de quatre points entourant l'une des quatre cases désignant les positions possibles des cibles. Dans le cas d'un indice de couleur unique, chaque case était entourée de quatre points, mais un de ces ensembles de points était de couleur unique, soulignant ainsi une position en particulier. Les résultats démontrent que même si la position de l'indice n'est pas corrélée avec la position de la cible (dans l'Expérience 3, la cible apparaissait à l'endroit indicé dans 25% des essais et à un endroit non indicé dans 75% des essais), ou même corrélée négativement avec la position de la cible (dans certains blocs d'essais des Expériences 1 et 2, la cible n'était jamais présentée à la position indicée), un indice invalide induit un coût dans les temps de réponse à la cible, à condition qu'il soit de même nature que la cible. En d'autres termes, lorsque les participants recherchent une cible définie par une apparition soudaine et qu'un indice consistant également en une apparition soudaine est présenté au préalable dans une position différente, l'attention est capturée par cet indice, provoquant un temps de réponse plus long à la cible que si le même indice avait été présenté dans la même position que la cible, ou que si aucun indice n'avait été présenté. Par contre, un indice de couleur unique n'influence pas la réponse à une cible à apparition soudaine de cette façon. L'inverse est vrai lorsque la tâche implique la recherche d'une cible de couleur unique : un indice de couleur unique capture l'attention, mais pas un indice à apparition soudaine (mais voir Lamy & Egeth, 2003, Expériences 2-4).

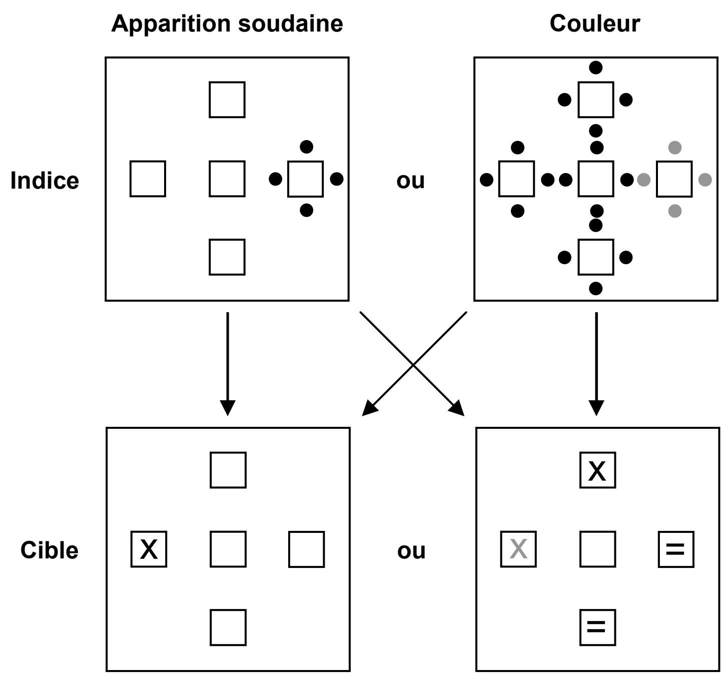

Figure 1. Illustration des conditions d'indiçage par apparition soudaine et par couleur unique, ainsi que des cibles définies par apparition soudaine et par couleur unique, dans le paradigme d'indiçage spatial modifié.

La propriété qui capture l'attention (apparition soudaine ou couleur unique) est donc la propriété qui est pertinente pour la réalisation de la tâche, c'est-à-dire la propriété qui définit la cible et qui fait l'objet d'une recherche visuelle. Selon Folk et al. (1992, 1993), les participants adoptent un ensemble de contrôles attentionnels descendants en fonction des exigences de la tâche. Une fois ces contrôles en place, la réponse du système d'orientation de l'attention dépend de la séquence de stimuli, de sorte que les items qui correspondent aux contrôles capturent l'attention de façon exogène, involontaire.

L'effet de capture contingente de l'attention a été répliqué à plusieurs reprises dans le cadre du paradigme d'indiçage spatial modifié, qui implique une incertitude quant à la position spatiale de la cible (Folk & Remington, 1998, 1999, 2006, Expérience 1; Folk, Remington, & Wright, 1994; Lamy, Leber, & Egeth, 2004, Expériences 1-2; Remington & Folk, 2001; Remington, Folk, & McLean, 2001). Il est postulé que la capture ainsi observée résulte d'un déplacement de l'attention visuospatiale vers la position de l'indice répondant aux critères des contrôles attentionnels descendants, et non d'une interférence à des stades plus précoces, comme le filtrage d'une scène visuelle plus chargée, un effet d'amorçage dû à la présentation visuelle de la propriété à rechercher, ou un retard dans le déploiement de l'attention vers la position de la cible, ni à des stades plus tardifs, comme la sélection de la réponse (Folk & Remington, 1998; Pratt & Hommel, 2003; Remington et al., 2001; Remington, Johnston, & Yantis, 1992). Premièrement, un effet de validité impliquant une interaction entre les positions de l'indice capturant l'attention et de la cible est observé, de sorte que la performance à la cible est améliorée si elle suit l'indice dans la même position, mais détériorée si elle est présentée ailleurs. Ceci indique qu'au moment de la présentation de la cible, l'attention était focalisée à la position spatiale de l'indice (Folk & Remington, 1998, 1999; Folk et al., 1992; Folk et al., 1994; Lamy et al., 2004, Expériences 1-2; Remington et al., 2001). De plus, lorsqu'une amorce est présentée à la position indicée, on observe un effet de compatibilité entre l'identité de l'amorce et celle de la cible, ce qui suggère que l'attention focale a été déployée vers la position de l'amorce, puisque celle-ci a été traitée (Ansorge & Heumann, 2004; Remington et al., 2001).

Toutefois, lorsque la position de la cible est connue à l'avance et avec certitude, incitant l'observateur à concentrer son attention à cet endroit, il semble que l'attention ne puisse pas être capturée par un indice apparaissant en dehors du foyer attentionnel, même s'il répond aux critères de sélection de la cible (Folk & Remington, 1996; Yantis & Jonides, 1990). Or, si le participant connaît avec certitude la position où la cible sera présentée, mais que plusieurs items sont présentés à cette position, faisant en sorte qu'il y a maintenant incertitude temporelle quant à l'identité de la cible, un item non pertinent situé hors du foyer attentionnel capture maintenant l'attention, suivant les contraintes des contrôles attentionnels.

C'est ce qui a été observé par Folk, Leber et Egeth (2002). Ils ont présenté aux participants une série de lettres défilant au centre d'un écran en présentation visuelle sérielle rapide (PVSR), à un rythme de 10 items par seconde, avec l’instruction de rapporter l’identité du seul chiffre portant la couleur cible inclus dans la séquence. Toutefois, malgré que les participants savaient que la cible allait toujours apparaître au sein de cette séquence centrale, leur performance à la cible était moins bonne si un distracteur périphérique, donc apparaissant dans une autre position que celle de la cible, et porteur de la même caractéristique que la cible (couleur unique dans l’Expérience 1, couleur spécifique dans les Expériences 2, 3, et 4) précédait la présentation de la cible de 100 ou 200 ms. Dans ces expériences, un ensemble de quatre distracteurs était utilisé. Il s’agissait de quatre signes dièse (#) présentés en haut, en bas, à gauche et à droite de la série PVSR. Les quatre distracteurs pouvaient être gris, ou encore trois étaient gris et le quatrième était coloré en rouge ou en vert. Parallèlement, la cible était soit l’unique item rouge ou l’unique item vert de la séquence PVSR. La condition de distracteur singleton de couleur cible (définie selon la couleur de la cible pour chaque participant) pouvait donc être comparée à une condition de distracteur singleton de couleur non-cible, à une condition de distracteurs sans singleton (les quatre distracteurs gris), ainsi qu’à une condition contrôle où aucun distracteur n’était présent. Le fait qu’un distracteur singleton quant à la couleur n’induise aucun coût de performance par rapport à la condition de distracteurs sans singleton, lorsque ce singleton ne possédait pas la caractéristique cible, appuie l’hypothèse de capture contingente de l’attention.

Même avec ce paradigme, où la sélection de la cible doit se faire de façon plutôt temporelle que spatiale, il semble que la capture relève de l'attention visuospatiale. En effet, Folk et al. (2002, Expériences 3 et 4) ont observé un effet d'amorçage par une lettre présentée en périphérie, à la position indicée par la couleur cible. Ce résultat, analogue à ceux du paradigme d'indiçage spatial, suggère en effet que l'attention visuospatiale a été déployée vers la position du distracteur périphérique, malgré que les participants savaient que la cible ne se trouverait jamais à cet endroit. Par contre, deux études ayant utilisé un paradigme semblable et des délais entre la présentation des distracteurs et la présentation de la cible (*stimulus onset asynchrony*, SOA) allant jusqu'à 500 ms ont trouvé que l'effet de capture perdurait pendant tout ce temps (Egeth, Folk, Leber, & Nakama, 2000; Lamy et al., 2004), Expérience 3). Ce résultat est surprenant si on assume que l'effet de comportemental observé est dû à un déploiement involontaire de l'attention visuospatiale vers la position du distracteur de couleur cible. En effet, si la capture attentionnelle est bien une capture de l'attention visuospatiale, on devrait s'attendre à ce que l'attention soit éventuellement désengagée de la position du stimulus ayant capturé l'attention et soit réorientée vers la séquence PVSR centrale. Deux interprétations sont alors plausibles : soit l'effet comportemental de capture attentionnelle cache un processus plus complexe, soit l'éventail de SOAs étudiés par Egeth et al. (2000) et Lamy et al. (2004, Expérience 3) n'était pas assez large pour observer un retour de la performance au niveau de base après la capture. Dans la première étude de ma thèse, j'ai exploré le décours temporel de l'effet de capture contingente de l'attention dans un paradigme semblable à celui de Folk et al, (2002), utilisant également une séquence en PVSR centrale qui incluait une cible définie par la couleur cible, et des distracteurs périphériques non pertinents.

L'hypothèse de la capture de l'attention par la saillance ascendante des stimuli

À l'encontre de l'hypothèse de capture contingente de l'attention, Theeuwes (1991, 1992, 1994, 1996) soutient que la capture attentionnelle est uniquement fonction de la saillance ascendante des stimuli, de sorte que l'item dont les caractéristiques physiques offrent le signal le plus fort capture l'attention, indépendamment des buts de l'observateur. Selon lui, les stades préattentifs de traitement et de sélection ne peuvent pas être influencés par les contrôles attentionnels descendants.

Theeuwes fonde sa théorie sur les résultats issus du paradigme de singleton additionnel. Dans ce paradigme, illustré dans la Figure 2, la tâche des participants est de rechercher un item, parmi un ensemble de recherche de taille variable, qui diffère des autres selon une caractéristique physique telle la forme ou la couleur, par exemple, rechercher un cercle parmi des losanges. Dans cette cible se trouve un stimulus sur lequel porte la réponse, par exemple, une ligne dont le participant doit rapporter l'orientation. Or, dans l'ensemble de recherche peut se trouver un second singleton, qui se distingue selon une dimension différente, par exemple, un cercle rouge alors que tous les autres items, incluant la cible, sont verts. Si le singleton distracteur est plus saillant que le singleton cible, par exemple si le rouge et le vert sont plus faciles à distinguer que les cercles et les losanges, alors l'attention est capturée par le distracteur et la réponse à la cible s'en trouve affectée. Par contre, si c'est le singleton cible qui est le plus saillant, alors il capture l'attention en premier et aucun effet du singleton distracteur n'est observé. Ainsi, Theeuwes (1991, 1992, 1994, 1996) en conclut que c'est la saillance ascendante qui détermine la capture de l'attention, sans égard aux contrôles attentionnels descendants requis par la tâche.

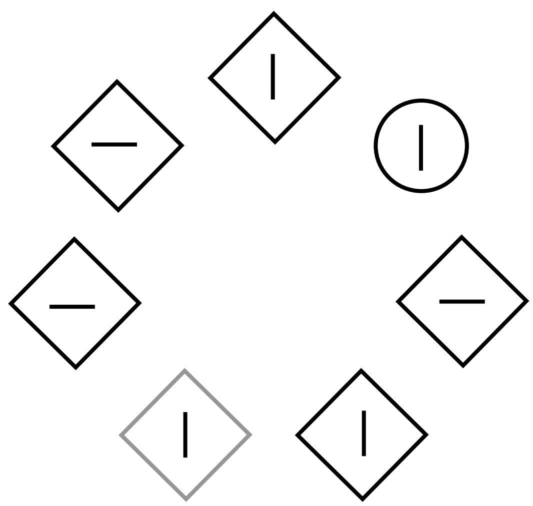

Figure 2. Illustration d'un ensemble de recherche dans le paradigme de singleton additionnel, contenant un singleton de forme, et un singleton de couleur.

Cette forme de capture causerait également un déploiement de l'attention visuospatiale vers la position du singleton le plus saillant. En effet, des effets de compatibilité entre la cible et l'item se trouvant à la position du distracteur causant la capture ont été rapportés (Theeuwes, 1996; Theeuwes & Burger, 1998), comme dans le cas de la capture contingente de l'attention.

Interprétations de la capture pure selon l'hypothèse de la capture contingente de l'attention

Les tenants de l'hypothèse de la capture contingente de l'attention ont proposé deux explications de la capture pure, c'est-à-dire strictement causée par les propriétés physiques des stimuli. D'une part, il se pourrait que l'interférence causée par des stimuli dont la saillance ascendante est très forte soit de nature non spatiale, mais résulte plutôt de coûts de filtrage (Folk & Remington, 2006; Folk & Remington, 1998, 1999). Selon cette hypothèse, les effets de compatibilité entre les items présentés aux positions des singletons distracteurs et cibles observés par le groupe de Theeuwes (Theeuwes, 1996; Theeuwes & Burger, 1998) pourraient être dus au traitement en parallèle de ces deux items. Dans ce cas, non pas l'ensemble de recherche en entier, mais seulement les deux items présentés dans des singletons, seraient traités. Ainsi, même avec des cibles qui requièrent généralement l'apport de l'attention focale, telles des lettres, la charge attentionnelle (deux items) serait assez légère pour permettre un traitement parallèle, et ainsi, une interférence entre les deux objets (Folk & Remington, 2006). Toutefois, des données issues de l'IRMf et de l'électrophysiologie appuient l'hypothèse d'un déploiement de l'attention visuospatiale vers un singleton saillant capturant l'attention, même en l'absence de contrôles attentionnels descendants en faveur de ses caractéristiques. En effet, l'IRMf a révélé des activations des aires liées au contrôle de l'attention visuospatiale, telles le cortex pariétal supérieur et certaines régions frontales, lorsqu'un distracteur de couleur unique était présent dans la tâche de singleton additionnel, où la cible était un singleton quant à la forme (de Fockert, Rees, Frith, & Lavie, 2004). De leur côté, Hickey, McDonald et Theeuwes (2006) ont observé une N2pc, un indice électrophysiologique du déploiement de l'attention visuospatiale (voir section plus bas, *La N2pc, indice électrophysiologique de l'orientation de l'attention visuospatiale*) en réponse à de tels distracteurs.

D'autre part, la capture par un singleton saillant pourrait être un cas spécifique de capture contingente de l'attention, si les contrôles attentionnels favorisent la sélection du singleton le plus saillant dans l'ensemble de recherche (Bacon & Egeth, 1994; Folk et al., 1994). Ainsi, Bacon et Egeth (1994) ont distingué deux modes de recherche : le mode de détection de singleton et le mode de recherche de caractéristiques. Le mode de détection de singleton est utilisé par un observateur lorsqu'il recherche une cible qui diffère de tous les autres éléments de son entourage par une caractéristique qui la rend unique. Par exemple, une cible bleue parmi des distracteurs qui sont tous jaunes, ou encore un carré parmi des cercles. Au contraire, le mode de recherche de caractéristiques est utile lorsque la cible est définie par une propriété en particulier, et non simplement par un aspect qui la distingue de tous les autres items. Par exemple, une cible bleue parmi des distracteurs jaunes, rouges, et verts. Dans ce cas, il ne suffit pas de rechercher le seul item qui diffère des autres, puisqu'ils sont tous différents les uns des autres; il faut réellement rechercher l'item bleu.

En effet, Bacon et Egeth (1994) ont utilisé le paradigme de singleton additionnel et ont répliqué l'effet de capture par le singleton saillant. Toutefois, lorsqu'ils ont modifié la tâche pour décourager l'adoption du mode de détection de singleton, soit en diversifiant l'ensemble de recherche ou en présentant deux ou trois exemplaires de la cible, lui retirant ainsi sa qualité de singleton, aucun coût de performance n'était associé à la présentation d'un singleton saillant.

L'adoption de l'un ou l'autre mode de recherche dépend de ce qui est véritablement exigé par la tâche, et non nécessairement des instructions. Par exemple, même si les instructions spécifient de répondre à la cible de forme unique, si l'ensemble de distracteurs est homogène, c'est-à-dire si tous les distracteurs sont identiques, le participant se contentera d'un mode de détection de singleton, puisque la cible est en effet un singleton. Donc, deux conditions doivent être remplies pour qu'un mode de recherche de caractéristiques soit adopté : la connaissance de la propriété qui définit la cible et l'hétérogénéité parmi l'ensemble de distracteurs (Bacon & Egeth, 1994; Folk et al., 2002; Folk & Remington, 1998; Folk et al., 1992; Lamy & Egeth, 2003, Expérience 5; Lamy et al., 2004). Même au sein du mode de recherche de caractéristiques, la spécificité des contrôles attentionnels peut varier selon les demandes de la tâche : des contrôles attentionnels peuvent être établis au niveau des dimensions, par exemple en faveur d'une discontinuité quant à la couleur, et non à la forme ou l'orientation (Bacon & Egeth, 1994; Folk & Remington, 1999; Folk et al., 1992; Folk et al., 1994), ou encore au niveau des valeurs, par exemple bleu, et non simplement n'importe quelle couleur unique (Folk et al., 2002; Folk & Remington, 1998; Lamy & Egeth, 2003, Expériences 5-6; Lamy et al., 2004).

L'hypothèse de capture pure avec désengagement rapide de l'attention

À l'opposé, les défenseurs de la capture par la saillance ascendante des stimuli ont proposé l'hypothèse de capture pure avec désengagement rapide pour expliquer les résultats appuyant la capture contingente de l'attention (Theeuwes, Atchley, & Kramer, 2000). Selon cette interprétation, les singletons ont bel et bien la capacité de capturer l'attention dans tous les paradigmes, étant donné que la sélection préattentive ne bénéficierait pas du contrôle attentionnel descendant. Toutefois, ce contrôle permettrait, une fois le distracteur sélectionné, d'inhiber le traitement plus avancé de ce distracteur et d'en désengager l'attention. Ainsi, dans les études utilisant le paradigme d'indiçage spatial modifié, l'effet des distracteurs singletons qui ne présentent pas la propriété pertinente à la tâche ne serait pas visible, puisque la cible est présentée au moins 150 ms après l'indice, laissant au système cognitif amplement de temps pour se désengager de la position du singleton non pertinent. Les indices possédant une caractéristique pertinente, quant à eux, seraient l’objet d’un plus long traitement attentionnel. Ainsi, Theeuwes et ses collègues admettent que les contrôles attentionnels descendants jouent bel et bien un rôle dans le traitement des stimuli, mais qu’ils ne peuvent pas prévenir la capture attentionnelle par des stimuli saillants aux stades très précoces de sélection.

En accord avec l’hypothèse de désengagement rapide de l’attention, Theeuwes et al. (2000) et Kim et Cave (1999) ont observé des décours temporels différents pour la capture par un singleton saillant et la capture par une propriété contingente aux contrôles attentionnels : dans des paradigmes de singleton additionnel, l’attention semblait être concentrée à la position du singleton le plus saillant dans les 150 ms suivant sa présentation (voir aussi Lamy & Egeth, 2003, Expériences 1 et 5), puis à la position du singleton cible, soit le deuxième item le plus saillant de l’ensemble de recherche, à des délais plus longs. De même, lorsque ce paradigme a été employé dans le cadre d’une étude électrophysiologique, un traitement spatialement sélectif du singleton le plus saillant, le distracteur, a été observé avec une latence plus courte que le même type de traitement pour la cible (Hickey et al., 2006). Ces résultats sont cohérents avec l’idée qu’un singleton saillant capture l’attention de façon préattentive, alors que les contrôles attentionnels descendants favorisent les stimuli possédant la caractéristique cible un peu plus tard dans la séquence de traitement.

Toutefois, l'étude de Theeuwes et al. (2000) a été critiquée pour la possibilité que des coûts de filtrage soient à l'origine des effets de capture par le singleton saillant aux délais distracteur-cible courts (Folk & Remington, 2006). En effet, dans cette étude, qui utilisait le paradigme de singleton additionnel, un ensemble comprenant un singleton distracteur était présenté à divers SOA avant la présentation de l'ensemble de recherche contenant le singleton cible. Ainsi, selon Folk et Remington (2006), plus le SOA entre l'ensemble contenant le singleton distracteur et celui contenant la cible diminuait et s'approchait d'une présentation simultanée des deux événements, plus la difficulté de déterminer lequel des deux singletons constituait la cible augmentait, résultant en un effet de SOA, et plus la probabilité augmentait que l'identité des deux singletons aient été traités en parallèle, générant l'effet de compatibilité observé et interprété par Theeuwes et al. (2000) comme un indice du déploiement de l'attention visuospatiale vers la position du singleton distracteur. La procédure utilisée par Kim et Cave (1999), qui présentaient un stimulus sonde à proximité de l'un ou l'autre des singletons (le distracteur saillant ou la cible) et qui mesuraient le temps de réaction à cette sonde selon sa position spatiale et le temps écoulé depuis la présentation de l'ensemble de recherche, n'est pas susceptible d'avoir été contaminée par des coûts de filtrage. Toutefois, les trois études présentaient des ensembles de recherche qui encourageaient l'adoption d'un ensemble de contrôles attentionnels laxiste, c'est-à-dire d'un mode de détection de singleton. En effet, lorsque l'étude de Kim et Cave (1999) a été répliquée avec un ensemble de recherche obligeant l'adoption d'un mode de recherche de caractéristiques, aucun effet attentionnel n'a été généré par le singleton saillant (Lamy, Tsal, & Egeth, 2003).

Par ailleurs, il a été démontré que des indices possédant une caractéristique pertinente à la tâche en cours généraient une plus grande N1 occipitale que ceux qui ne correspondaient pas aux contrôles attentionnels (Arnott, Pratt, Shore, & Alain, 2001). Étant donné que cet indice électrophysiologique reflète l'activité d'aires visuelles, ce résultat suggère que les contrôles attentionnels descendants permettent bel et bien de moduler le traitement visuel précoce des stimuli. De plus, il est à noter qu'un item qui présente une caractéristique pertinente à la tâche n'a pas besoin d'être un singleton pour capturer l'attention de façon contingente aux contrôles attentionnels, ce qui renforce la position selon laquelle la saillance en soi n'est pas déterminante pour la capture de l'attention (Lamy et al., 2004, Expérience 3). En fait, une étude employant l'IRMf a démontré que même un distracteur qui n'est pas un singleton, s'il correspond aux contrôles attentionnels descendants, active non seulement le réseau attentionnel dorsal fronto-pariétal, lié au contrôle volontaire de l'attention, mais également le réseau ventral fronto-pariétal, réputé répondre aux propriétés physiques des stimuli (Serences et al., 2005).

Qui plus est, des études en IRMf ont observé que l'activation de ce réseau du système attentionnel, ventral fronto-pariétal, dépend largement de la pertinence des stimuli en question pour la tâche, de sorte que si un stimulus ne possède pas de caractéristique de la cible, il ne provoque pas l'activation de se réseau (Indovina & Macaluso, 2007; Kincade et al., 2005).

En résumé, toutes ces données appuient l'hypothèse de capture de l'attention. Toutefois, la résolution temporelle des techniques comportementale et d'imagerie ne permet pas de réfuter l'hypothèse de désengagement rapide avec certitude. En revanche, la technique des potentiels liés aux événements (PLE) permet de suivre en continu le traitement des stimuli, même lorsque ceux-ci ne requièrent pas de réponse comportementale observable, et ce, avec une excellente résolution temporelle (voir section plus bas : *La technique des potentiels liés aux événements*). La deuxième étude de ma thèse utilise les PLE dans le but de confronter les hypothèses de capture contingente de l'attention et de capture pure avec désengagement rapide.

L'ORIENTATION DE L'ATTENTION PAR DES ATTRIBUTS DE HAUT NIVEAU

Toutes les études mentionnées plus haut ont démontré des effets de capture contingente à des propriétés de bas niveau, telles l'apparition soudaine, la couleur et le mouvement. Toutefois, étant donné la complexité de l'environnement naturel, il apparaît simpliste de penser que les mécanismes attentionnels n'opèrent que sur la base de propriétés d'aussi bas niveau que la couleur ou le mouvement. Dans la troisième étude de ma thèse, j'ai exploré la possibilité que la capture puisse être contingente à une propriété de plus haut niveau, définie par un attribut conceptuel et non par des caractéristiques physiques, c’est-à-dire la catégorie alphanumérique.

Le débat sur la capacité de la catégorie alphanumérique à guider l’attention n’est ni jeune, ni résolu. Récemment, dans une revue de la littérature dont le but était d’identifier les attributs qui ont cette capacité, Wolfe et Horowitz (2004) n’ont pu conclure sur le cas de la catégorie alphanumérique, qu’ils ont qualifié de douteux. Ce questionnement trouve son origine dans les années 1970, alors qu’un effet de catégorie alphanumérique a été observé dans plusieurs études employant des paradigmes de recherche visuelle, effet qui a été répliqué à de nombreuses reprises (Brand, 1971; Dixon & Shedden, 1987; Gleitman & Jonides, 1976, 1978; Ingling, 1972; Jonides & Gleitman, 1972, 1976; Polk & Farah, 1998). Cet effet consistait en une recherche plus efficace de la cible si celle-ci et les distracteurs appartenaient à des catégories opposées (par exemple, une lettre cible parmi un ensemble de chiffres) que s’ils appartenaient à la même catégorie (par exemple, une lettre parmi un ensemble de lettres). Une interférence semblable entre items de la même catégorie, et réduite pour des items de catégories différentes, a été observée dans le cadre du paradigme de clignement attentionnel (Dux & Coltheart, 2005).

Par contre, il est difficile d’affirmer que cet effet de catégorie alphanumérique est bel et bien dû à la valeur conceptuelle de l’appartenance à l’une ou l’autre des catégories, puisque les lettres et les chiffres diffèrent également sur le plan des caractéristiques physiques (Cardosi, 1986). Toutefois, cette interprétation est contestée, puisqu'il est difficile de concevoir qu'il existe effectivement un ensemble de caractéristiques physiques exclusif aux chiffres, et un autre, exclusif aux lettres, de sorte que chaque item ressemble plus aux items de sa catégorie qu'aux items de la catégorie opposée (Deutsch, 1977).

La contribution des caractéristiques de bas niveau dans l'effet de catégorie alphanumérique a été évaluée empiriquement à plusieurs reprises, dans des études où l'on tentait d'apparier la similarité intra- et inter-catégorie. Dans certains cas, l'effet de catégorie a survécu à ces manipulations (Dixon & Shedden, 1987, Expérience 2; Dux & Coltheart, 2005; Gleitman & Jonides, 1976, Expérience 1; Ingling, 1972; Jonides & Gleitman, 1972), mais dans plusieurs études, il s'est avéré que c'étaient les différences de bas niveau entre lettres et chiffres qui déterminaient le patron de résultats (Cardosi, 1986; Duncan, 1983; Krueger, 1984).

Plus récemment, des données issues d'études en imagerie cérébrale ont suggéré que le cerveau pourrait être doté d'aires spécialisées pour le traitement des lettres et, possiblement, des chiffres (Baker et al., 2007; Polk & Farah, 1998; Polk et al., 2002). En effet, malgré que la connaissance des lettres et des chiffres soit acquise à un âge relativement avancé, considérant le développement du cerveau, l'expérience très étendue et régulière avec ces classes de stimuli serait suffisante pour expliquer le développement d'aires corticales qui leur soient dédiées (Polk & Farah, 1998).

Étant donné l'ensemble des observations comportementales et neurophysiologiques concernant le traitement de la catégorie alphanumérique, il est possible que le système cognitif soit en mesure d'établir des contrôles attentionnels descendants en faveur de cette propriété. Si tel était le cas, alors le signal ascendant de tels stimuli pourrait être modulé par les contrôles attentionnels descendants et résulter en un effet de capture de l'attention contingente à la catégorie alphanumérique.

Mais alors, est-ce que cet effet de capture serait dû à un déplacement de l'attention visuospatiale vers la position d'un item appartenant à la catégorie cible, comme cela semble être le cas pour la capture par des propriétés de bas niveau (voir section plus haut, *L'hypothèse de la capture contingente de l'attention*)? Bien qu'il ait été proposé qu'un item pouvait être localisé sur la base de son appartenance à une catégorie alphanumérique spécifique (Jonides & Gleitman, 1976), il serait plausible qu'une propriété plus complexe génère des interactions entre les processus ascendants et descendants à un niveau de traitement plus avancé (Deutsch, 1977; Gleitman & Jonides, 1978). D'ailleurs, il a été démontré que même lorsqu'elles ne provoquent pas de déploiement de l'attention visuospatiale, des propriétés favorisées par des contrôles attentionnels descendants peuvent induire un effet de capture attentionnelle contingente, en influençant le temps alloué au traitement des distracteurs (Ghorashi, Zuvic, Visser, & Di Lollo, 2003).

LA TECHNIQUE DES POTENTIELS LIÉS AUX ÉVÉNEMENTS

Il est bien connu qu'il est possible d'enregistrer l'activité électrique du cerveau à l'aide d'électrodes placées sur le scalp. Cette activité se nomme l'électroencéphalogramme (EEG), et comprend l'activité générée par des centaines de sources neuronales, correspondant à d'innombrables processus sensoriels, cognitifs et moteurs qui ont cours à tout moment dans le cerveau. Toutefois, il est possible d'isoler certaines de ces réponses spécifiques grâce à la à la technique des PLE. Comme leur nom l'indique, les PLE reflètent l'activité déclenchée par un événement en particulier, des stades sensoriels jusqu'à la réponse motrice (Luck, 2005).

Afin de les extraire du signal EEG, les PLE sont obtenus par une procédure de moyennage (Luck, 2005). Il s'agit de répéter la stimulation dont on veut étudier la séquence de traitement à de nombreuses reprises, en enregistrant la réponse EEG à chaque fois. On aligne ensuite chacun de ces segments d'EEG selon l'événement d'intérêt, généralement l'apparition du stimulus, mais parfois également la réponse du participant à ce même stimulus, et on en calcule la moyenne. Une grande partie de l'EEG brut est composé de réponses qui ne sont par liées à l'événement en question. Ainsi, cette partie des signaux ne présente aucune régularité par rapport à l'événement et sera donc annulée par la procédure de moyennage. La moyenne obtenue, soit les PLE, consiste en une série de déflections positives et négatives, appelées composantes. Les composantes sont nommées d'après leur polarité, négative ou positive, et leur latence (e.g., la P300 est une composante positive qui atteint son maximum environ 300 ms après la présentation d'un stimulus) ou leur ordre d'apparition (e.g., la N2 est la deuxième composante négative). Alors que les premières composantes, comme la P1 et la N1, reflètent des processus sensoriels et perceptuels, plus l'on avance dans la séquence des PLE, plus les composantes sont affectées par des processus cognitifs ou liés à la réponse. En enregistrant l'EEG à de nombreux sites sur le scalp, il est possible d'obtenir une topographie de l'activité électrique à un moment donné dans la séquence de traitement, qui permet une localisation grossière des processus reflétés par les PLE. Toutefois, la résolution spatiale de la technique des PLE est très basse.

La technique des PLE comporte donc deux principaux avantages pour étudier la capture attentionnelle. Tout d'abord, ils peuvent être enregistrés et analysés même en l'absence d'une réponse explicite à un stimulus. Dans le cas précis de la capture, cela signifie que le traitement d'un distracteur pourra être observé directement, plutôt qu'inféré indirectement à partir des modulations des réponses à la cible. Deuxièmement, les PLE offrent une excellente résolution temporelle, de l'ordre de la milliseconde. Ceci permettra de dissocier les hypothèses de capture contingente de l'attention et de capture par la saillance ascendante avec désengagement rapide de l'attention, puisqu'elles se distinguent par leurs prédictions quant au décours temporel précis de la réponse d'orientation aux distracteurs.

La N2pc, indice électrophysiologique de l'orientation de l'attention visuospatiale

La composante d'intérêt pour les présents travaux est la N2pc. La N2pc (*N2 p*ostérieure *c*ontrolatérale) est ainsi nommée parce qu'elle reflète une polarité plus négative aux sites postérieurs controlatéraux au stimulus d'intérêt, par rapport aux sites ipsilatéraux, et ce, dans l'intervalle temporel de la N2, c'est-à-dire entre 180 et 280 ms environ suivant la présentation de ce stimulus (Luck & Hillyard, 1994). Le calcul de la N2pc implique de soustraire l'activité des électrodes ipsilatérales de l'activité des électrodes controlatérales au côté de présentation du stimulus d'intérêt. Cette procédure permet d'éliminer tout signal relié à de l'activité non latéralisée, et donc présente dans les deux hémisphères. Parmi les signaux ainsi ignorés, on compte le traitement de stimuli présentés au centre du champ visuel, les processus de sélection et d'exécution de la réponse, ainsi que le traitement sensoriel et perceptuel de stimuli présents de façon équilibrée dans les champs visuels gauche et droit.

La N2pc est considérée comme un index de l'orientation de l'attention visuospatiale, en temps réel. En effet, il semble que la N2pc reflète la sélection attentionnelle d'un stimulus visuel, suivant le déploiement de l'attention vers la position occupée par ce stimulus (Kiss, Van Velzen, & Eimer, 2008), tout d'abord à cause sa distribution controlatérale, et donc contingente à la position du stimulus d'intérêt, et parce qu'elle semble être générée par des aires pariétales et occipito-temporales, impliquées dans l'implémentation de la sélection attentionnelle (Hopf et al., 2000). De plus, plusieurs manipulations expérimentales ont permis d'observer que plus la demande attentionnelle liée au traitement d'un stimulus est grande, plus la N2pc à ce même stimulus est grande. Par exemple, une cible définie par une conjonction de caractéristiques plutôt que par une caractéristique unique, ou alors entourée d'un plus grand nombre de distracteurs, génère une plus grande N2pc (Luck, Girelli, McDermott, & Ford, 1997). Il en va de même pour des stimuli qui requièrent un examen méticuleux pour être identifiés comme cible ou distracteur (Luck & Hillyard, 1994). La N2pc reflète également les déplacements de l'attention prédits par les modèles sériels de recherche visuelle (Woodman & Luck, 2003). Luck et ses collègues (Luck, 1995; Luck et al., 1997; Luck & Hillyard, 1994) ont d'abord proposé que la N2pc reflétait la suppression des distracteurs. Toutefois, de plus en plus d'études favorisent une interprétation de la N2pc qui implique un traitement préférentiel de la cible (Brisson & Jolicoeur, 2007; Eimer, 1996; Eimer & Kiss, 2008; Hickey, Di Lollo, & McDonald, 2008).

OBJECTIFS ET HYPOTHÈSES DE RECHERCHE

PREMIÈRE ÉTUDE

Le premier objectif de cette étude était d'étudier le décours temporel de l'effet de capture contingente de l'attention dans un paradigme où la cible fait l'objet d'une sélection non spatiale. En effet, dans ce cas, il avait été observé que les coûts dans la performance à la cible, symptomatiques de l'effet de capture, persistaient jusqu'à au moins 500 ms suivant l'événement distracteur (Egeth et al., 2000; Lamy et al., 2004, Expérience 3). Cette absence de rémission de la performance à la suite de la capture était surprenante dans le cadre d'une interprétation visuospatiale de cet effet, laissant envisager que des processus plus complexes intervenaient probablement également, prévenant l'allocation de l'attention au traitement de la cible. Nous avons donc utilisé un paradigme similaire à celui de Folk et al. (2002), dans lequel nous avons manipulé l'intervalle temporel entre la présentation des distracteurs et celle de la cible, de 0 ms (les deux événements étant alors présentés au même moment) à 933 ms. Si l'effet comportemental de la capture contingente est bel et bien dû à un déplacement de l'attention visuospatiale vers la position du distracteur de couleur cible, alors nous devrions observer une interférence de ce distracteur d'assez courte durée, suivie d'un retour au niveau de performance de base aux délais distracteurs-cible les plus longs. Si, au contraire, l'effet de capture résulte, en totalité ou en partie, d'une interférence à des stades de traitement plus avancés, comme le traitement en profondeur du distracteur de couleur cible, requérant des ressources cognitives limitées, ou encore une interférence au niveau de la sélection de la réponse, alors il est possible qu'il existe un déficit de performance dans la condition de distracteur de couleur cible par rapport au niveau de base, et ce même près d'une seconde après la présentation du distracteur.

Un objectif secondaire de cette étude était de démontrer qu'il n'était pas nécessaire qu'un distracteur soit perceptuellement saillant pour capturer l'attention. En effet, Folk et ses collègues (2002) avaient montré que le statut de singleton n'était pas suffisant pour engendrer une capture de l'attention; la correspondance entre la couleur cible et la couleur du distracteur était, quant à elle, nécessaire pour que cet effet se produise. Toutefois, un ensemble de quatre distracteurs était toujours utilisé, et lorsqu'un distracteur de couleur cible était présent, il était accompagné de trois distracteurs gris. De cette façon, il est possible que les trois distracteurs gris aient fait l'objet d'un groupement perceptuel, et que le distracteur de couleur se soit vu conférer une saillance subjective plus grande, contribuant ainsi à l'effet de capture. Lamy et al. (2004, Expérience 3) ont démontré que cet aspect n'était pas critique en utilisant un plus grand ensemble de distracteurs et en présentant, entre autres, une condition dans laquelle l'ensemble de distracteurs était hétérogène, chacun présentant une couleur différente. De cette façon, il était impossible pour le distracteur de couleur cible de paraître plus saillant que les autres distracteurs de l'ensemble, or, un effet de capture contingente par le distracteur de couleur cible a quand même été obtenu. Dans la présente étude, la stratégie opposée a été employée afin de répliquer cette conclusion. Seulement deux distracteurs composaient l'ensemble de distracteurs, présentés à gauche et à droite de la séquence PVSR dans laquelle était incluse la cible. Cette manipulation faisait en sorte que d'un point de vue du signal ascendant, les deux stimuli, soit le distracteur gris et le distracteur de couleur, étaient également saillants. Selon l'hypothèse de capture contingente de l'attention, et suivant les résultats de Lamy et al. (2004, Expérience 3), même dans ces conditions, seule la présence un distracteur de couleur cible devrait entraîner une baisse de performance dans le rappel de la cible.

Deuxième étude

La deuxième étude visait deux objectifs principaux. Le premier était de confirmer que la capture contingente de l'attention résultait d'un déplacement de l'attention visuospatiale vers la position du distracteur possédant la caractéristique pertinente à la tâche. Le deuxième, et le plus important, était de confronter l'hypothèse de capture contingente de l'attention et l'hypothèse de capture pure avec désengagement rapide de l'attention.

À ces fins, le même paradigme que dans la première étude a été utilisé, à l’exception de la manipulation du délai entre l’apparition des distracteurs et celle de la cible, et l’EEG a été enregistré, dans le but d’étudier la N2pc aux distracteurs périphériques. Ce paradigme était tout indiqué pour étudier la N2pc puisque la procédure de soustraction impliquée dans le calcul de la N2pc permet d’éliminer toute activité reliée à une présentation non latéralisée. Dans le cas présent, ceci signifie que le signal généré par la séquence PVSR centrale et le traitement de la cible a été éliminé, permettant l’observation du traitement des stimuli présentés en périphérie, c’est-à-dire les distracteurs.

Si la capture de l’attention par un distracteur saillant est automatique et inévitable, mais que les contrôles attentionnels descendants permettent à l’observateur de désengager rapidement son attention de cet item pour la réorienter vers un item possédant la caractéristique pertinente à la tâche, alors une N2pc devrait être observée en réponse à un distracteur de couleur, peu importe que ce soit celle que l’observateur recherche (la couleur cible) ou non. Cette N2pc devrait être plus brève pour un distracteur de couleur non cible que pour un distracteur de couleur cible, pour lequel un désengagement rapide n’est pas prédit. Par contre, si l’hypothèse de la capture contingente est juste, et que seuls les items possédant une caractéristique favorisée par les contrôles attentionnels descendants capturent l’attention, alors seuls ces items, soit les distracteurs périphériques de couleur cible, devraient susciter une N2pc.

Troisième étude

Dans la dernière étude, la capture de l'attention contingente à une propriété de haut niveau a été testée. Un paradigme semblable à celui utilisé dans les deux premières études a été employé, mais modifié de façon à ce que la propriété pertinente soit maintenant la catégorie alphanumérique. Ainsi, la séquence PVSR centrale était constituée de lettres grises et d'un chiffre gris ou vice-versa, et les deux distracteurs périphériques, lorsque présents, étaient toujours gris. Ils pouvaient compter deux symboles dièse (#), un symbole et un chiffre, un symbole et une lettre, ou encore un chiffre et une lettre.

Dans un premier temps, je présente une expérience comportementale dans laquelle le délai distracteurs-cible et les propriétés des distracteurs périphériques (présence ou absence de la catégorie cible) ont été manipulés afin de déterminer si la capture pouvait effectivement être contingente à la catégorie. Ensuite, je propose trois expériences ayant recours à la N2pc pour élucider la nature, attentionnelle visuospatiale ou non, de l'effet des distracteurs. L'une de ces expériences emploie une procédure très rigoureuse pour s'assurer que tout effet de la catégorie s'explique par la valeur conceptuelle de l'appartenance à une catégorie, et non par les différences physiques potentielles entre l'ensemble des chiffres et celui des lettres.

S’il est possible de mettre en place des contrôles attentionnels descendants en faveur d’une catégorie alphanumérique et de les employer pour moduler le traitement précoce de stimuli alphanumériques, alors on devrait observer une baisse de la performance dans le rapport d’une cible présentée au centre lorsqu’un distracteur périphérique appartenant à la même catégorie la précède, mais pas lorsqu’il s’agit d’un distracteur de la catégorie opposée. De plus, si un tel effet existe et que l’interférence se situe au niveau de l’attention visuospatiale, une N2pc en réponse aux distracteurs périphériques devrait être observée. Une absence d’N2pc dans ce cas pourrait signifier que la présence d’un distracteur de catégorie cible interfère avec le traitement de la cible à des stades de traitement plus tardifs, possiblement au niveau des représentations.

D’autre part, s’il est impossible d’utiliser une propriété de haut niveau telle la catégorie alphanumérique pour guider l’orientation de l’attention ou le traitement des stimuli, alors aucun effet de capture attentionnelle ne devrait être observé, ni dans les données comportementales, ni dans les PLE.

Une troisième possibilité serait que l’effet de catégorie alphanumérique repose sur les caractéristiques physiques. Dans ce cas, lorsque les différences entre les chiffres et les lettres sont contrôlées, un effet de capture devrait être observé lorsqu'un chiffre ou une lettre est présenté en périphérie, peu importe la catégorie cible.

ARTICLE 1 : THE TIME COURSE OF THE CONTINGENT SPATIAL BLINK

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É.L. & P.J. : Interprétation des résultats.

É.L. : Collecte et analyse des données, première rédaction de l’article.

P.J. : Conception du projet, révision du manuscrit.

ABSTRACT

Attentional capture is the unintentional deployment of attention to a task-irrelevant but attentionally-salient object. The contingent involuntary orienting hypothesis states that it occurs only if a distractor's property matches current top-down attentional control settings (Folk, Remington, & Johnston, 1992). Folk, Leber, and Egeth (2002) found that monitoring a central RSVP stream for a coloured target led to spatial attentional capture by a peripheral distractor that matched the target colour. Using a similar paradigm, we explored the time course of this spatial blink. Implications of this study for current accounts of the attentional capture phenomenon are discussed.

SOMMAIRE

La capture attentionnelle consiste en un déploiement involontaire de l'attention vers un objet saillant, bien que non pertinent à la tâche. L'hypothèse de la capture contingente de l'attention (Folk, Remington, & Johnston, 1992) soutient que ce phénomène ne se produit que si un distracteur possède une propriété qui correspond aux réglages du contrôle attentionnel descendant, c'est-à-dire ce qui est pertinent à la tâche en cours. Le fait que l'attention spatiale soit focalisée peut aussi constituer une forme de contrôle descendant : des études d'indiçage spatial suggèrent que dans ces conditions, des stimuli saillants apparaissant à des positions non pertinentes ne capturent pas l'attention (e.g., Yantis & Jonides, 1990).

Cependant, dans ces protocoles, un seul item était présenté à la l'endroit indicé, éliminant ainsi l'incertitude à la fois au sujet de la position de la cible, et à propos de quel objet constitue la cible. Folk, Leber et Egeth (2002) ont exploré l'effet d'un distracteur présenté à l'extérieur du centre du champ attentionnel, lorsque les réglages attentionnels concernent la sélection non spatiale d'une cible incluse dans une séquence centrale en présentation visuelle sérielle rapide (PVSR). Le sujet était alors susceptible de capture par un distracteur périphérique de même couleur que la cible, mais pas par un distracteur gris ou d'une couleur autre. Ces résultats suggèrent que ce clignement spatial est fonction de réglages attentionnels descendants, et non simplement de discontinuités périphériques.

En utilisant un paradigme similaire, nous avons exploré le décours temporel de ce phénomène. Une séquence centrale en PVSR de chiffres colorés était présentée aux participants. Dans cette série était inclus un chiffre cible, défini par sa couleur et devant être identifié de façon différée. À un certain moment durant la séquence, deux distracteurs périphériques (deux dièses) apparaissaient de part et d'autre de la série centrale. Trois conditions de distracteurs ont été utilisées : un gris et un de même couleur que la cible; un gris et un de couleur différente de celle de la cible; ou deux distracteurs gris. Neuf délais distracteur-cible furent testés : le distracteur pouvait survenir en même temps que la cible (délai 0), ou de 117 à 933 ms avant la cible, par intervalles de 117 ms (délais de 1 à 8 items dans la séquence PVSR).

Nous avons recueilli les données de 48 étudiants ayant pris part à cette expérience. Une ANOVA utilisant la condition de distracteurs et le délai comme facteurs intra-sujets a révélé que les deux effets principaux étaient significatifs ($p < .0001$ et $p < .006$, respectivement). L'interaction distracteur x délai était aussi significative ($F(16, 736) = 5{,}34$, $p < .0001$), ce qui s'explique par la performance dans la condition de distracteur de même couleur que la cible, qui subit une baisse aux délais courts, mais qui rejoint le niveau obtenu dans les deux autres conditions au délai 5.

Nous avons donc reproduit les résultats de Folk et al. (2002) concernant l’effet de la condition de distracteurs. Ainsi, nos résultats appuient l’hypothèse de la capture contingente de l’attention, tout en procurant une analyse plus fine et complète du décours temporel du phénomène de capture attentionnelle.

INTRODUCTION

Attentional capture is a phenomenon in which attention is unintentionally deployed to a task-irrelevant but attentionally-salient object. In a typical attentional capture task, either in spatial cuing or in visual search studies, subjects search for a target embedded in an array of items, one of which possesses a feature that is a potential attractor of attention. Capture is said to occur if responses are facilitated when the target itself possesses the salient feature, and inhibited when the salient object is a distractor. Effects of capture can be measured using accuracy rate (e.g. Folk, Leber, & Egeth, 2002) or reaction times (e.g. Jonides & Yantis, 1988).

Different properties of stimuli were described as producing attentional capture. Some studies have argued that abrupt onsets are special in that they have such distracting potential (Jonides & Yantis; 1988, Yantis, 1993). However, static features, such as colour and form, have also been demonstrated to capture attention under some conditions (Bacon & Egeth, 1994; Folk et al., 2002; Folk & Remington, 1998; Folk, Remington & Johnston, 1992; Theeuwes, 1992, Turatto & Galfano, 2000). Theeuwes (1992) proposed that it is the bottom-up salience of singletons that determines whether they attract attention against subjects' intentions. Bacon and Egeth (1994), on the other hand, found that singletons capture attention only when the target is also a singleton, suggesting that subjects then adopt a singleton detection mode, rather than a feature detection mode, that would allow top-down control to prevent singletons from capturing attention.

To account for these apparently contradictory results, Folk et al. (1992) proposed the contingent involuntary orienting hypothesis, which states that involuntary shifts of attention to a given stimulus are contingent on top-down attentional control settings. Namely, attentional capture depends on whether an item shares a property that is critical to the performance of the current task; this usually transcribes as the property defining the target to identify. Nevertheless, they argue that given those settings, the on-line response to events is purely stimulus-driven, without any intervention by high-level cognitive processes (Folk, Remington, & Johnston, 1993). Congruently, they observed that if subjects are searching for a target defined by a static discontinuity (e.g. colour or form), any object also containing a static, but not dynamic discontinuity (e.g., movement, abrupt onsets or offsets), will capture attention, and vice versa (Folk et al., 1992; Folk, Remington, & Wright, 1994). They later extended the scope of these attentional control settings to include specific values of static discontinuities, under conditions of feature value heterogeneity within the array of distractors (Folk & Remington, 1998). Hence, a subject searching for a red target will only be susceptible to capture by a red distractor, and not by a green distractor. The degree to which attention is spatially focused may also constitute a form of top-down control: Several results from spatial cuing studies support the view that when spatial attention is in a highly focused state, salient stimuli appearing at non-target locations do not capture attention (Yantis and Jonides, 1990; Theeuwes, 1991).

However, in these experiments, only one item ever occurred at the cued location, eliminating uncertainty not only about the target location, but also about which object was the target. Folk et al. (2002) sought to explore the effect of an irrelevant distractor appearing outside the focus of spatial attention when attentional settings were concerned with nonspatial selection of a target. They designed a task in which the target, a coloured letter, was embedded within a central rapid serial visual presentation (RSVP) stream, therefore requiring attention to be focused at fixation. At some interval during the central letter sequence, four # distractors appeared above, below, left and right of the central letter. Four distractor-target lags were used: 0, 1, 2 and -1 (the target then appearing before the distractor). There were also four distractor conditions: no distractor, four grey distractors, one nontarget-colour and three grey distractors, and one target-colour and three grey distractors. In Experiment 1, all stimuli in the central RSVP stream were grey except for the target; one of the peripheral distractors in the two last conditions was also coloured, and the frame-to-frame SOA was 84 ms. However, in Experiment 2, which we are extending here, each of the non-target letters in the RSVP stream was one of four possible colours, and SOA varied from 84 ms (32.6% of the trials) to 100 ms (50.1% of the trials) to 117 ms (17.3% of the trials). Results in this latter experiment showed that when subjects were looking for a target of a specific colour, they exhibited capture of spatial attention by peripheral distractors that were the same colour as the target, but not by grey distractors, or distractors of a different colour, indicating that this capture was driven by top-down attentional control settings, and not merely by a colour discontinuity or a salient colour in the periphery.

One possible problem with Folk et al.'s paradigm however, is that the single coloured distractor is presented along with three identical items, both in terms of colour and shape. Because of this high similarity, those distractors would tend to be perceptually grouped, resulting in pop-out of the coloured distractor (Duncan & Humphreys, 1989). One could therefore argue that Folk et al.'s (2002) results are partly due to distractor bottom-up salience, instead of top-down attentional control settings solely. To address this question, we used a paradigm similar to that of Folk et al. (2002, Experiment 2), but with a simplified distractor display of only two # signs, presented left and right of the central stream, instead of four. The same distractor conditions as in Folk et al.'s (2002) Experiment 2 were used, except for the no distractor condition which was not included; the grey distractors condition served as a control condition. Thus, when a coloured distractor was presented, it could not pop-out against a homogeneous group of items, because there was only a single other distractor (grey). Lamy, Leber and Egeth (2004, Experiment 3) also explored whether a non-singleton distractor could capture attention in Folk et al.'s (2002) paradigm. However, instead of simplifying the distractor display, they used eight # distractors, uniformly spaced around fixation, and varied the degree of homogeneity between distractors, yielding six conditions: no distractor; homogeneous (eight identical distractors); heterogeneous (eight differently coloured distractors, without the target-colour); target-colour singleton; target-colour heterogeneous; and nontarget-colour singleton. Figure 1 reproduces parts of the results obtained by Lamy et al. (2004) that are particularly interesting for the present study. As can be seen in the figure, they found a drop in target identification in the target-colour singleton as well as in the target-colour heterogeneous conditions, indicating that singleton pop-out is not necessary for contingent attentional capture to occur. These results suggest that we should observe capture only when one of the # signs was in the target colour.

The main purpose of our experiment was to measure the time course of the contingent spatial blink observed by Folk et al. (2002). Folk et al. (2002, Experiment 2) only used four distractor-target lags, and found that the largest capture effect occurred at lag 2 (i.e., at a distractor-target SOA of approximately 200 ms). Two studies using this paradigm failed to show recovery from the capture effect with distractor-target SOAs reaching 500 ms. First, Egeth, Folk, Leber, and Nakama (2000) presented results obtained with the exact same methodology as that of Folk et al. (2002, Experiment 2), but using SOAs of 0, 100, 200, 300, 400, and 500 ms. Again, capture was evident only if one of the distractors was in the target colour, and the largest effect was observed at SOAs of 200 to 500 ms, showing no sign of attenuation over time. The second study is that of Lamy et al. (2004, Experiment 3). In this case, four distractor-target SOAs were used: 0, 100, 200, and 500 ms. As in the previous studies, target identification was most disrupted at a SOA of 200 ms, with no recovery at the longest SOA (see Figure 1). Based on a spatial capture account of the phenomenon, however, one would expect that attention would eventually return to the central RSVP stream, following a capture event. If so, performance should return to baseline levels. It is puzzling that performance appeared to show no recovery by 500 ms post distractor onset in the studies of Egeth et al. (2000) and Lamy et al. (2004). Either something more complex is occurring, and we can think of several possibilities, or simply, previous investigations have not included sufficiently long SOAs to observe the return of focused attention to the central RSVP stream.

Given these considerations, we wished to measure the time course of the capture effect over a relatively long window and with fine-grained sampling in the time domain, in order to observe a possible recovery from the attentional capture effect. To achieve this goal, we used nine distractor-target SOAs, ranging from 0 to 933 ms.

EXPERIMENT

METHOD

Subjects

A total of 48 undergraduate students took part in this study (67% female, 33% male, mean age: 22.2 years old), 24 with each set of colours (see below). They were paid for their participation, which consisted of a single session of approximately 45 minutes. All reported having normal or corrected-to-normal visual acuity and colour vision.

Apparatus and stimuli

The experiment was run on a Pentium IV computer using Mel 2.0 software. The stimuli were presented on a computer monitor placed in a dark room and viewed from a distance of approximately 50 cm.

The stimuli were coloured digits 2 to 9, measuring 1.3° and presented as an RSVP stream at fixation. Four colours, in addition to grey, were used in each colour set: green, red, ochre, and blue. One colour was designated as the target colour, and was therefore attributed to only one item in the stream; the other digits changed randomly between the remaining three colours and grey (consecutive stimuli always had a different colour). One of the digits in the series was flanked by two # distractors, appearing 2° left and right of the central character. Depending on the distractor condition, the two #s could be grey, or one could be grey and the other could have either the target colour or one of the remaining colours.

Two sets of colours were used: Set A had similar luminance values and contained more easily differentiable colours and Set B had more brilliant colours. The luminance values (cd/m^2) and CIE (x,y) coordinates for Set A were: green (30.0, 0.291, 0.592), red (27.7, 0.566, 0.326), ochre (35.0, 0.492, 0.441), blue (35.2, 0.172, 0.167), and grey (29.0, 0.288, 0.300). For Set B, the colour parameters were as follows: green (36.2, 0.290, 0.592), red (44.4, 0.369, 0.267), ochre (38.1, 0.476, 0.453); blue (42.3, 0.179, 0.194), and grey (36.8, 0.288, 0.300).

Design and procedure

Each trial was initiated by the subject by pressing the space bar. The fixation point remained on the screen for 200 ms, followed by an RSVP stream containing between 16 and 22 items presented for 117 ms each, without any blank intervals. Figure 2 shows the time course of events in a trial.

For each subject, three distractor conditions were used: One grey and one target-colour, one grey and one nontarget-colour, or two grey distractors (control condition). Coloured distractors were at the left or right equally often. These conditions were mixed within blocks.

Within a trial, the target digit, defined by its colour, could appear at the same time as the distractors (lag 0), or in one of the next eight frames (lags 1 to 8), yielding SOAs ranging from 0 ms to 933 ms. The target was always masked, being followed by at least one non-target digit. The target colour remained the same throughout the entire experiment for each subject, and was counterbalanced so that an equal number of subjects were tested with each target colour.
The experiment was comprised of 27 practice trials, in addition to 540 experimental trials divided into five blocks. Subjects were instructed to keep their eyes at fixation during each trial and were given written and oral instructions about the task and the stimuli. They were asked to make an unspeeded response regarding the identity of the target digit using the computer keyboard, guessing if they were unsure.

Subjects were given feedback regarding the accuracy of their response at the beginning of the next trial, the fixation point being a plus sign (+) if the answer was correct, otherwise turning into a minus sign (–).

RESULTS

The mean percentages of correct target identifications were subjected to an ANOVA with colour set as a between-subjects factor, and with distractor condition and lag as within-subjects factors. Neither the main effect of colour set nor any of its interactions with distractor condition and lag was significant ($p > .30$ in all cases); therefore it was not considered in further analyses.

The mean percentage of correct responses to the target for each distractor condition and distractor-target SOA is presented in Figure 3. An ANOVA with distractor condition and lag as within-subjects factors was performed. Both main effects were significant, $F(2, 94) = 17.26$, $MSE = 72.45$, $p < .0001$, and $F(8, 376) = 2.76$, $MSE = 96.20$, $p < .006$, respectively, but more importantly the distractor condition by lag interaction was also significant, $F(16, 752) = 5.33$, $MSE = 66.27$, $p < .0001$. As can be observed in Figure 3, this effect is driven by performance in the target-colour distractor condition, in which accuracy drops at lags 1 and 2, but rejoins the same level as the other conditions by lag 5. A separate ANOVA considering only the nontarget-colour distractor condition and the control condition confirmed that there was no significant difference between these two conditions, $F(1, 47) = 1.60$, $MSE = 63.76$, $p > .21$, and no distractor condition by lag interaction, $F(8, 376) = 1.55$, $MSE = 58.14$, $p > .13$. However, there was a significant effect of lag, $F(8, 376) = 4.38$, $MSE = 79.10$, $p < .0001$. Given that there was no interaction between lag and condition, when the control and nontarget-colour conditions were considered separately, we averaged these conditions to estimate control performance most accurately. We then performed nine new ANOVAs, taking each lag one at a time, and compared accuracy in the target-colour condition with accuracy in the average control condition. Significant differences were found at lags 0, $F(1, 47) = 5.49$, $MSE = 67.02$, $p < .02$, 1, $F(1, 47) = 56.86$, $MSE = 62.04$, $p < .0001$, and 2, $F(1, 47) = 13.71$, $MSE = 85.60$, $p < .009$. A marginal effect was found at lag 3, $F(1, 47) = 2.84$, $MSE = 83.34$, $p < .10$, and lag 4, $F(1, 47) = 2.19$, $MSE = 51.92$, $p < .15$. The differences were not significant at longer lags ($p > .22$ in all cases).

DISCUSSION

The experiment had two main purposes. First we wished to discover whether we could obtain the patterns of results reported by Folk et al. (2002), but with a simplified distractor array. In the Folk et al. experiments, the distractor items consisted of four symbols, presented above, below, and to the left and right of the central RSVP stream. In the present experiment we used only two distractor symbols, both # signs, one to the left and one to the right of the central RSVP stream. We wished to discover whether this simplified display would be sufficient to produce the effects observed by Folk et al. (2002). The reason for this manipulation was to reduce the degree to which the single coloured distractor element could pop out from the other distractors, by virtue of a salient discontinuity in its colour relative to the colour of the other distractors. As the number of other distractors is increased, they would tend to form a group, particularly to the extent that they all shared both colour and shape features (Duncan & Humphreys, 1989). In the present design, with a single other distractor (grey), there would be no sense in which the target-colour distractor would pop out from a homogeneous group of distractors.

Despite our simpler distractor layout, the results across the distractor conditions revealed the contingent capture effect reported by Folk et al. (2002). Relative to a control condition consisting of two grey distractors, a condition consisting of a single grey distractor accompanied by a salient nontarget-colour distractor produced no spatial attentional capture. In contrast, a grey distractor accompanied by a target-colour distractor produced significant spatial capture. Evidently, singleton pop out of the distractor is not required in order to produce the contingent capture effect. The present results therefore corroborate the conclusions reached by Lamy et al. (2004) from their use of the paradigm with heterogeneous distractor displays.

The second goal of the experiment was to measure the time course of the contingent capture effect with a more fine-grained sampling in the time domain than in previous work. As can be seen in Figure 3, accuracy in the target-colour distractor condition was clearly below that of the other two conditions only at SOAs of 0, 117, and 233 ms, with marginal effects at 350 and 467 ms. These results allow us to specify with some precision the time course of the effect, which presumably requires first a registration of the target colour in the peripheral stimulus, a capture of attention by this stimulus, followed by a return of attention to the central RSVP stream. The results thus reveal that this spatial capture effect is associated with relatively rapid shifts of attention between the central stream and the location of the coloured distractor. A liberal interpretation of the results would place an upper bound on the total duration of this "attentional travel" at about 350 ms, suggesting that each shift (out and back) would require no more than about 175 ms. We are supposing here that attention did not dwell long at the distractor location, but supposing that some time was lost in such dwell, then the attentional shifts themselves would be correspondingly shortened.

We note that the present paradigm produced a maximum difference between distractor conditions at an SOA of 117 ms. In contrast, in several experiments, larger effects were found at an SOA of 200 ms than at 100 ms (Egeth et al., 2000; Folk et al., 2002; Lamy et al., 2004). These studies also failed to observe recovery of accuracy even at a distractor-target SOA of 500 ms, whereas our results, which included measurements out to more than 900 ms, show that the effect quickly returns to baseline. We also note that, despite a similar performance level in the control conditions, the magnitude of the effect was smaller in the present study, approximately 12% at most, than in the previous ones, which exhibited interference effects reaching roughly 20% in Egeth et al. (2000) and Lamy et al. (2004), and approximately 40% in Folk et al. (2002). Furthermore, several aspects of the methodology used in our experiment distinguish our study from the three studies mentioned above. First, we used an inter-item SOA of 117 ms, rather than 100 ms as was used in the other studies. Our stimulus duration was also 117 ms, whereas Lamy et al. (2004) presented each stimulus for 50 ms, followed by a 50-ms blank interval. Egeth et al. (2000) and Folk et al. (2002) used a similar procedure, presenting each stimulus for a mean duration of 56 ms, also followed by a blank interval. The distractor eccentricity that was used in the present experiment was also smaller (2°) compared to that of the other studies discussed (5.2°). In addition, our stimuli were digits instead of letters, and our distractor display was smaller, that is, two distractors versus four in the Egeth et al. (2000) and Folk et al. (2002) studies, and eight in the Lamy et al. (2004) study. Considering that there were considerable differences in the magnitude of the effect as well as in the methodology employed, a plausible account for the time-course discrepancies observed between previous studies and the present one might be that any factor affecting the magnitude of the blink, such as stimulus duration, distractor salience, or eccentricity, may also affect its duration.[1] Therefore it would be useful to explore the effects of these parameters on the magnitude and time course of the contingent capture effect.

Finally, we note that, although very modest in absolute magnitude, there was a significant effect of SOA when we considered just the control and the nontarget-colour conditions, which produced statistically comparable results. This pattern consisted of a generally U-shaped function that was at a minimum at SOAs of 467 and 583 ms, with higher performance at shorter and longer lags, with a possible dip at 0 ms. Part of this pattern may have been produced by an alerting effect associated with the appearance of the distractors, because they were always either coincident with the target or prior to the target. The appearance of the distractor thus would signal that the target appearance was imminent. This effect would tend to dissipate over time, leading to the dip in performance at intermediate lags (Posner, 1978). On this view, it is not clear why performance increased slightly at longer lags, however. The results of Folk et al. (2002) contained no hint of any cost associated with the presentation of multiple grey distractors, compared with no distractor, and it seems likely that this was also the case in the present experiment, suggesting that the dip was probably not due to a general cost associated with the presentation of irrelevant information in the periphery.

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FOOT NOTE

[1] We thank Andrew Leber for this suggestion.

FIGURE CAPTIONS

Figure 1. Mean percentages of correct target identification as a function of distractor-target SOA and distractor condition in the Lamy et al. (2004, Experiment 3) study.

Figure 2. Illustration of the sequence of stimuli, each presented for 117 ms, in a trial with one grey and one target-colour distractor and a distractor-target SOA of 233 ms. Characters printed in black represent the target colour, dark grey characters were non-target colours, and light grey characters were grey.

Figure 3. Mean percentages of correct target identification as a function of distractor-target SOA and distractor condition, with 95% within-subjects confidence intervals appropriate for comparing a point with any other point (Loftus & Masson, 1994).

FIGURE 1

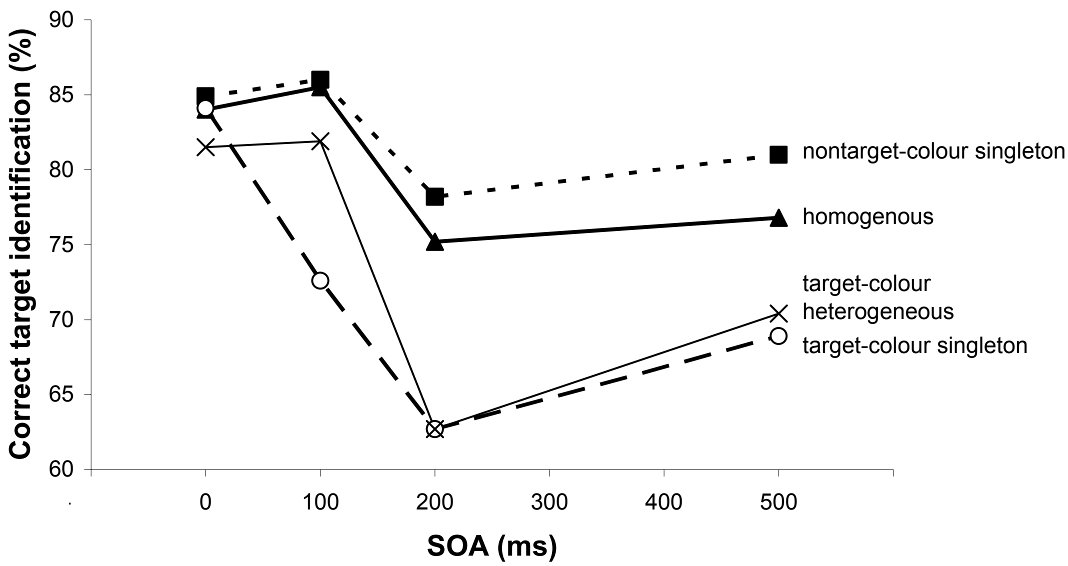

Correct target identification (%)
90
85
80
75
70
65
60
0
100
200
300
400
500
SOA (ms)
nontarget-colour singleton
homogenous
target-colour
heterogeneous
target-colour singleton

FIGURE 2

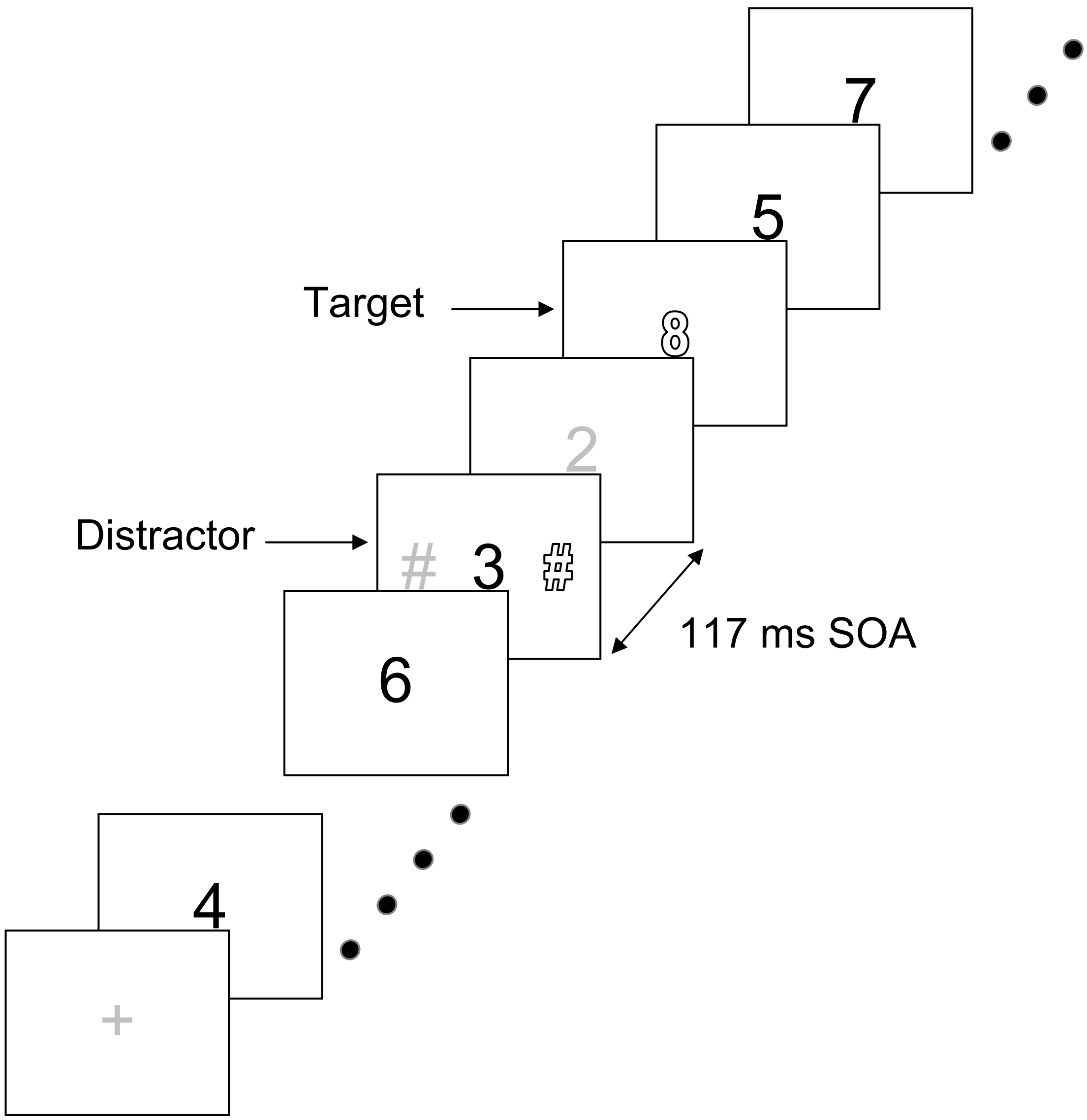
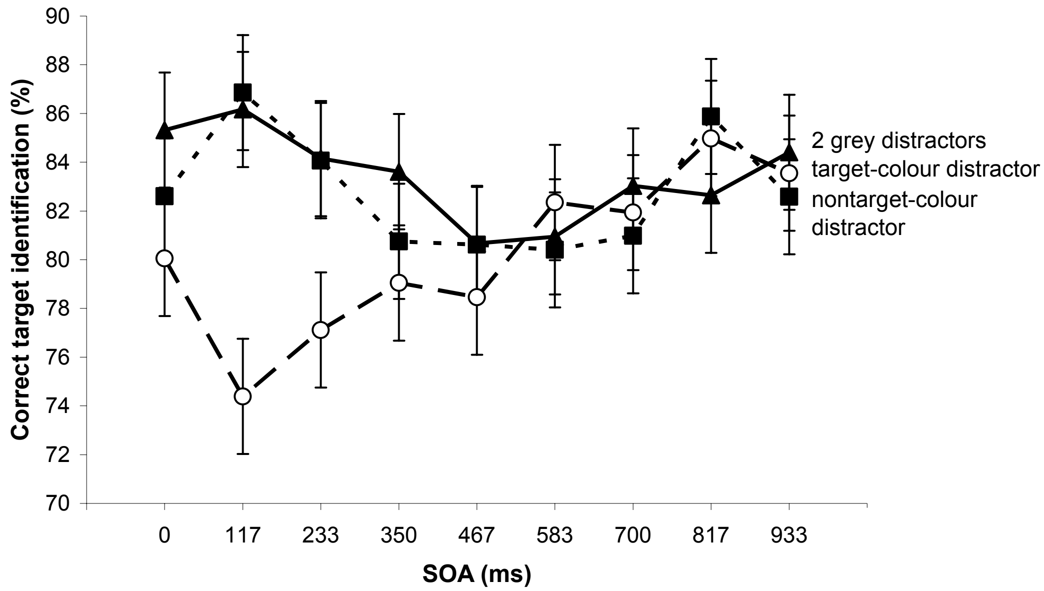


FIGURE 3


90
88
86
84
82
80
78
76
74
72
70
Correct target identification (%)
0
117
233
350
467
583
700
817
933
SOA (ms)
2 grey distractors
target-colour distractor
nontarget-colour distractor

ARTICLE 2 : TRACKING THE LOCATION OF VISUOSPATIAL ATTENTION IN A CONTINGENT CAPTURE PARADIGM

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Contribution des coauteurs :

É.L., D.J.P., & P.J. : Conception du projet et interprétation des résultats.

É.L. : Programmation des expériences, analyse des données (Expériences 1, 2, 4, et 5), et rédaction de la majorité de l'article.

D.J.P. : Analyse des données (Expérience 3) et rédaction des sections *General Methods* et *Methods* de l'article.

P.J. : Révision du manuscrit.

ABSTRACT

Currently, there is considerable controversy regarding the degree to which top-down control can affect attentional capture by salient events. According to the contingent capture hypothesis, attentional capture by a salient stimulus is contingent on a match between the properties of the stimulus and top-down attentional control settings. In contrast, bottom-up saliency accounts argue that the initial capture of attention is determined solely by the relative salience of the stimulus and the effect of top-down attentional control is limited to effects on the duration of attentional engagement on the capturing stimulus. In the present study, we tested these competing accounts by utilizing the N2pc event-related potential component to track the locus of attention during an attentional capture task. The results were completely consistent with the contingent capture hypothesis: an N2pc wave was elicited only by distractors that possessed the target-defining attribute. In a second experiment we expanded upon this finding by exploring the effect of target-distractor similarity on the duration that attention dwells at the distractor location. In this experiment, only distractors possessing the target-defining attribute (colour) captured visuospatial attention to their location and the N2pc increased in duration and in magnitude when the capture distractor also shared a second target attribute (category membership). Finally, in three additional control experiments, we replicated the finding of an N2pc generated by distractors, only if they shared the target-defining attribute. Thus, our results demonstrate that attentional control

settings influence both which stimuli attract attention and to what extent they are processed.

INTRODUCTION

Due to the limited capacity of our cognitive systems, as human beings we are often unable to process simultaneously all of the information present in a visual scene. Fortunately, attentional mechanisms allow us to isolate and preferentially process a subset of objects or a region of the visual field suspected of containing relevant information. Attention can be guided in either a voluntary or involuntary fashion. Voluntary shifts of attention are usually driven by the goals of the individual, while involuntary shifts occur in response to the characteristics of the stimuli, the most salient stimuli attracting attention exogenously.

Although there is general agreement that a sufficiently intense and salient stimulus can capture attention, there is a controversy regarding the degree to which the observer's goals and search strategies can affect attentional capture. According to the contingent attentional capture hypothesis (Folk, Remington, & Johnston, 1992), a distractor elicits an involuntary shift of attention to the location it occupies if it matches top-down attentional control settings, that is to say, if it shares a characteristic that is relevant for attentional selection in the task at hand. Hence, if an observer’s task is to respond to a red target, the presentation of a concurrent red distractor will often impair performance, but the presentation of a blue or yellow distractor will not (Folk, Leber, & Egeth, 2002; Folk & Remington, 1998; Lamy, Leber, & Egeth, 2004; Leblanc & Jolicoeur, 2005; Serences et al., 2005). Such contingent capture effects have been observed for colour, shape, movement, and sudden onset (Bacon & Egeth, 1994; Folk, Remington, & Wright, 1994).

In contrast, Theeuwes (1991, 1992, 1994, 1996) argues that attentional capture depends solely on the sensory salience of stimuli, and that the item generating the strongest bottom-up signal within the visual display will attract attention regardless of the observer's goals. Evidence for this purely bottom-up account of attentional capture is based primarily on results from the "additional singleton" paradigm. In this paradigm, Theeuwes and colleges have demonstrated that, when the task requires searching for a singleton target (e.g., an item with a unique shape), the presence of a distractor singleton in a task irrelevant dimension (e.g., colour) produces a significant response time cost for responses to the target. In order to account for apparently contingent capture effects from other paradigms, Theeuwes, Atchley, and Kramer (2000) have proposed that attention is initially captured by all salient stimuli, but then rapidly disengages from stimuli that do not match the task-relevant features. Thus, when the interval between distractor and target is sufficiently long, no effect of the non-matching distractor will be observed on the behavioural response to the target. Theeuwes et al. (2000) provided support for this proposal by examining the effect of distractor singletons across several distractor-target intervals. They found that significant attention capture effects were only observed for targets that onset less than 150 ms after the onset of the distractor. This suggests that attention was initially captured by the distractor singleton but was able to disengage within 150 ms. However, the observed capture effect could be due to the observers adopting a singleton search mode, in which they searched for items that differ from the homogeneous distractors. In paradigms similar to the ones used by Theeuwes et al. (2000), when participants are forced to adopt a feature search mode, monitoring for the presence of a specific feature that is relevant to the task at hand, no attentional effects arise from the presence of salient distractors that do not match the target feature even if they differ from the other distractors in some other way (Bacon & Egeth, 1994; Lamy, Tsal, & Egeth, 2003). Moreover, a distractor that matches the top-down attentional control settings does not have to be a singleton or create a pop-out effect within the visual search array to capture attention (Lamy et al., 2004; Leblanc & Jolicoeur, 2005).

According to Folk and his colleagues, contingent capture effects on behavioural performance are mediated by a shift of visuospatial attention to the location of the effective distractors that match the observer's attentional control settings. If this location does not match that of the actual target, a lengthening of response time, and/or a decrease in accuracy can be observed. However, a number of non-spatial explanations of the interference observed in capture studies have been proposed. For example, filtering costs associated with the presence of additional items in the visual display, the distractors, might be responsible for at least part of the behavioural impairments observed in attentional capture tasks (Folk & Remington, 1998; Remington, Johnston, & Yantis, 1992), and these costs might be greater for distractors resembling the target. The presence of a distractor possessing the target-defining attribute might also cause delayed allocation of attention to the target, because of the greater difficulty of identifying the target location. In trials containing a distractor matching the top-down control settings, two items possessing the target-defining feature are present: the distractor and the target. Therefore, the observer must gather more information about each location where the target-defining feature is present (the target location and the distractor location), before deciding which location holds the target and deploying his attention accordingly (Remington et al., 2001). There is also a possibility of the distractor being processed as if it were a target, leading to a lengthening of response times and to intrusions of the identity of the distractor in response selection (Ghorashi, Zuvic, Visser, & Di Lollo, 2003). Several behavioural studies have addressed these possibilities and yielded results consistent with the visuospatial interpretation of contingent capture. For example, Folk and colleagues (Folk & Remington, 1998; Folk et al., 1992) have found an interaction between the effective distractor and target locations, responses being facilitated when the distractor preceded the target in the same location, and impaired when the target followed the distractor in a different location. Similarly, compatibility effects of the identity of the effective distractor on target processing have been observed, such as might be expected if attention was focused on the distractor (Ansorge & Heumann, 2004; Remington, Folk, & McLean, 2001; Theeuwes, 1996; Theeuwes & Burger, 1998). Finally, the time course of the contingent capture effect seems to be consistent with rapid shifts of attention to and from the distractor location (Leblanc & Jolicoeur, 2005; Remington et al., 2001). However, overt responses depend on a wide range of processes and it is difficult to identify the stages of processing at which differences in behavioural performance arise.

Recently the visuospatial attentional shift interpretation of capture has received support from studies that have utilized functional magnetic resonance imaging (fMRI) to examine brain activity during attentional capture tasks. These studies have revealed that brain areas associated with the control of visuospatial attention are active during attentional capture tasks. In one such study, de Fockert, Rees, Frith, and Lavie (2004) utilized a visual search paradigm in which participants were required to search for a singleton target defined by a unique shape. When a colour singleton distractor was present, increased activity was observed in the superior parietal cortex, bilaterally, and in the left lateral precentral gyrus of the frontal lobe, compared to when only nonsingleton distractors were present. Additionally, in a study in which participants had to identify a coloured target presented within a central rapid serial visual presentation (RSVP) stream while target- or nontarget-coloured distractors could appear in the periphery, Serences et al. (2005) found greater fMRI activation to target-coloured distractors than to nontarget-coloured distractors in contralateral regions of the extrastriate visual cortex responding to the location of the distractor. Target-coloured distractors also generated larger fMRI activations than nontarget-coloured distractors in the intraparietal sulcus (IPS), frontal eye field (FEF), anterior supplementary motor area (pre-SMA), ventro-frontal cortex (VFC) and right temporo-parietal junction (TPJ). The areas identified by the de Fockert et al. (2004) and Serences et al. (2005) studies have all been linked to a network controlling visuospatial attention (Corbetta & Shulman, 2002), hence these results are consistent with a visuospatial account of attentional capture. Although the modulation of activation observed in extrastriate visual cortex observed by Serences et al. (2005) suggests that attention was engaged at the location of the target-coloured distractors, the poor temporal resolution of fMRI makes it impossible to determine the latency and duration of this effect. Importantly, it is likely that fMRI would be insensitive to the very brief attentional engagement predicted by Theeuwes et al.'s (2000) account of contingent capture.

Event-related potentials (ERPs) provide an alternative technique to investigate brain activity. ERPs allow the continuous observation of the processing of stimuli with fine temporal resolution, even in the absence of overt behavioural responses (Luck, 2005). Hence, in the case of attentional capture, ERPs permit a more direct way to monitor the processing of irrelevant distractors, without having to rely on inferences made from observed modulations of the response to the subsequent target and, unlike fMRI, allow the time course of this processing to be determined. For instance, Arnott and colleagues (2001) showed that irrelevant cues possessing the target-defining feature (colour or abrupt onset) elicited a larger occipital N1 component than cues that did not match the top-down attentional control settings. This result suggests that the cognitive set adopted by the observer modulated how the cues were processed in early visual areas, but did not allow the study of the spatial dynamics of contingent capture.

The N2pc is an ERP component often utilized as an index of the locus of visual attention. It is measured as a greater negativity over posterior electrode sites contralateral, relative to ipsilateral, to an attended stimulus, present approximately 170 to 280 ms post stimulus onset (Luck & Hillyard, 1994). The N2pc is thought to reflect the attentional selection of a visual stimulus following a shift to a peripheral location, because brain activity generating the N2pc is specifically contingent on the location of the stimulus, showing a contralateral distribution, and seems to originate from parietal and occipito-temporal areas, involved in the implementation of attentional selection (Hopf et al., 2000). In addition, a larger N2pc is generated by a target on which a complex discrimination task must be performed, requiring further processing of the target after it has been selected on the basis of the target-defining feature, than by a target simply to be detected according to the mere presence of the target-defining feature (Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994). A larger N2pc is also observed when a target is surrounded by more distractors (Luck et al., 1997) or by distractors that are less easily differentiated from the target (Luck & Hillyard, 1994), all situations that require a greater contribution of focal attention. Moreover, the N2pc seems to reflect the locus of attention following shifts of attention predicted by serial models of visual search (Woodman & Luck, 2003). It has also been suggested that the N2pc reflects the top-down selection of a target according to the presence of task-relevant properties (Eimer, 1996).

It has recently been demonstrated that distractors that automatically capture attention elicit an N2pc (Hickey, McDonald, & Theeuwes, 2006). In that study, a visual search task was used in which the target was defined as a shape singleton (a circle among diamonds or a diamond among circles) and a distractor, always a colour singleton (a red item among green items or a green item among red items), could be present in the search array. Behavioural capture was observed when an irrelevant colour singleton distractor was present, and an N2pc to such colour distractors was found. Hickey et al.'s (2006) study, therefore, demonstrated that attentional capture by a salient item does involve allocation of visuospatial attention to the location of the salient distractor, but did not allow studying the allocation of visuospatial attention during contingent attentional capture because both targets and distractors were singletons, thus allowing subjects to adopt a singleton search mode rather than a feature search mode (Bacon & Egeth, 1994).

The primary aim of the present study was to test the contingent capture (Folk et al., 1992) and the brief attentional dwell time (Theeuwes et al., 2000) accounts of capture by tracking the location of visuospatial attention in a capture paradigm using distractors that did not differ in terms of bottom-up salience. We utilized the N2pc component of the ERP to track the spatial locus of attention following the presentation of distractors that did or did not match top-down attentional control settings established in the context of a task requiring a feature search mode (Leblanc & Jolicoeur, 2005). In this paradigm, participants searched for a target-coloured digit embedded in a RSVP stream of heterogeneously coloured digits. Capture was induced by presenting two irrelevant, peripheral pound signs ("#") along with the digit preceding the target digit in the RSVP stream. One of the peripheral distractors was grey, and the other was presented in the target colour or in a nontarget colour. Leblanc and Jolicoeur (2005) and Folk et al. (2002) found attentional capture, indexed by a drop in accuracy of reports of the identity of the target digit, when a target-coloured distractor, but not a nontarget-coloured distractor, preceded the presentation of the target. Moreover, identical behavioural performance was observed whether a nontarget-coloured distractor, only grey distractors, or no distractor was presented prior to the target (Folk et al., 2002). If this contingent capture effect is due to top-down attentional control settings affecting the ability of bottom-up signals to capture visuospatial attention, we should see an N2pc in response to the presentation of a target-coloured distractor — indicating that the locus of spatial attention, initially at fixation, would have moved to the location of the target-coloured distractor — but not to the presentation of a nontarget-coloured distractor. In contrast, if the contingent capture effect is due to a difference in the duration that attention dwells at the distractor location on target-coloured and nontarget-coloured distractor trials, an N2pc should be observed in response to all distractors. However, the duration of the

N2pc should be longer on target-coloured than on nontarget-coloured distractor trials. A third possibility is that the contingent capture interference is due to non-spatial mechanisms, in this case, no N2pc would be observed in either distractor condition.

The secondary aim of the present study was to determine if the capture effect could be modulated by the processing of the peripheral distractor. Recently, Ghorashi et al. (2003) have provided evidence that the time taken to process distractors is an important contributor to the effect of contingent capture on reaction time. In order to explore this issue, we designed a second experiment with an additional category manipulation: the peripheral distractor either shared or did not share the target colour and/or category. If top-down attentional control settings influence how stimuli are processed, it is possible that attentional engagement at the location of distractor stimuli may be enhanced for distractors that are similar to the target. Consequently, the magnitude or the duration of the N2pc elicited by distractors that match the target category may be enhanced relative to that elicited by distractors that do not match the target category.

Three additional control experiments were conducted. Experiment 3 replicated the results of Experiment 1 while reducing the temporal predictiveness of the distractor display. In Experiment 4, we replaced the RSVP stream by a search array consisting of three coloured digits aligned vertically, in order to eliminate ERP responses to the sequence of rapidly changing items at fixation. Finally, in Experiment 5, we equated the number of times each colour could be presented in the periphery, to control for differences in the relative frequency of presentation of the various colours appearing at the two peripheral locations. An N2pc only to the target-coloured distractor was found in each experiment, which provides strong support for visuospatial contingent capture.

GENERAL METHODS

In all five experiments the subjects viewed a computer monitor from a distance of 57 cm and a chin rest was used to stabilize the head. The luminance of all stimuli was 12.8 cd/m^2. Responses were made on a standard computer keyboard. Subjects were instructed to maintain fixation on the centrally presented stimuli and to blink between trials. Trials were self-paced and subjects initiated each trial by pressing the spacebar. All subjects were naïve volunteers and were paid $20 (Canadian) dollars for participation in a single 2-hour session. All subjects reported normal or corrected-to-normal vision. The study was approved by the local ethics review board at the Université de Montréal.

The electroencephalogram (EEG) was recorded from the left and right mastoids and 64 standard 10-10 scalp sites with active Ag/AgCl electrodes (Biosemi Active Two system) mounted on an elastic cap. Eye position was monitored by both the horizontal and vertical electro-oculogram (EOG). EEG and EOG channels were low-pass filtered at 67 Hz and digitized at 256 Hz. After acquisition the EEG channels were referenced to the average of the left and right mastoids and high-pass filtered at 0.01 Hz (half power cut-off). Trials containing blinks, eye movements and EEG artefacts were removed prior to ERP averaging by applying automated artefact detection routines. Subjects whose average eye position deviated more than ~0.2° (3.2 μV) from the center (according to the procedure described by Luck, 2005) or who had less than 65% of the trials remaining after the trial rejection procedure were excluded from further analyses.

ERP averages were calculated from EEG epochs time-locked to the presentation of the distractors. Separate ERPs were calculated for each distractor condition and visual field (left or right) of the coloured distractor. In Experiments 1, 2 and 3, participants observed a RSVP stream comprised of items that changed every 117 ms. Consequently, the ERP curves showed a steady-state like modulation that corresponded to the presentation rate of items in the RSVP stream. In order to isolate the N2pc wave from this ongoing activity, N2pc difference waves for each distractor condition were computed for the electrode pairs O1/O2, PO3/PO4, and PO7/PO8. ERP waveforms from electrodes ipsilateral to the coloured distractor were subtracted from those from contralateral electrodes and the resulting difference waves for each visual field were averaged to produce the N2pc waves. The N2pc waveforms were pooled across the three electrode pairs, low-pass filtered at 25 Hz and baseline corrected by subtracting the mean voltage during the 200 ms pre-stimulus period. The N2pc amplitude was quantified by measuring the mean amplitude of the pooled N2pc wave for each subject and each distractor condition in a measurement window that approximately corresponded to the time interval between the point in time that the N2pc reached half of its maximum amplitude during onset and when the N2pc again reached half amplitude during its offset.

EXPERIMENT 1

METHODS

Stimuli and procedure

The task was to identify a digit of a specified colour within a RSVP stream of coloured digits. The RSVP stream was presented in the center of a black screen. Each of the digits within the stream were 1.3° of visual angle high and coloured either red, blue, green, ochre, or grey. The four colours and grey were equiluminant. One of the four colours was designated as the target colour for each subject with the target colour counterbalanced across subjects.

A schematic representation of the stimulus sequence is depicted in Figure 1a. Each trial began with the presentation of a fixation point that served as response accuracy feedback for the previous trial. A “+” indicated that the response on the previous trial was correct and a “-” indicated that the previous response was incorrect. After an interval of 200 ms following the initiation of the trial by the participant (press of the spacebar), the fixation point was replaced by the RSVP stream. The stream consisted of a series of 16 to 22 digits. Each digit in the stream was presented for 117 ms without any interstimulus interval between digits. The colour of each nontarget digit in the stream was selected at random from the three nontarget colours and grey, with the restriction that no two consecutive digits could be presented in the same colour. The identity of each digit in the stream was also randomly selected from the digits 2 through 9, and again, the same digit could not be presented twice in a row. The serial position of the target digit in stream was randomly selected from positions 8 through 11. One serial position before the target digit, a pair of distractors was presented, one to each side of the RSVP stream. The choice of the distractor-target lag was guided by Leblanc and Jolicoeur (2005), who found maximum interference at an SOA of 117 ms. The distractors, 1.3° high “#” symbols, were presented 2° from the central stream for 117 ms simultaneously with the RSVP item prior to the target. Each pair of distractors consisted of one grey “#” symbol and one coloured symbol. The location, left versus right, of the coloured distractor varied randomly across trials. In the target-colour distractor condition, the coloured symbol had the same colour as the target digit. In the nontarget-colour distractor condition, the coloured symbol colour was selected at random from the nontarget colours on each trial. Distractor condition was selected randomly on each trial with the constraint that each distractor condition occurred on 50% of trials in each block.

————INSERT FIGURE 1 ABOUT HERE————

At the end of the RSVP stream subjects were required to report the identity of the target digit using the numeric keypad on the computer keyboard and without moving their eyes. Rapid responding was not required and subjects were instructed to attempt to be as accurate as possible. Subjects were also instructed to ignore the lateral distractors. Each experimental session consisted of 20 practice trials followed by 608 experimental trials, divided in four blocks. Each block consisted of an equal number of trials for each distractor condition and coloured distractor side.

Subjects

Twenty one subjects participated in Experiment 1 (7 male, mean age: 23.7). Five subjects were excluded from data analysis. One subject was excluded due to an equipment malfunction during recording. Three subjects were excluded because an excessive number of trials were rejected due to artefacts, blinks, and eye movements. Finally, one subject was rejected due to excessive residual horizontal EOG activity after artefact rejection, indicating that the artefact detection procedure was not completely successful in eliminating trials with lateral eye movements. The remaining 16 subjects (4 male) had a mean age of 24.2 years. For these subjects, an average of 87.2% of the trials was included in the ERP analysis.

Results and Discussion

Behavioural results

Mean accuracy of target identification is shown in Table 1a. As expected, mean accuracy was higher in the nontarget-colour than in the target-colour distractor condition, replicating the attentional capture by the target-coloured distractor that had been observed by Folk et al. (2002) and Leblanc and Jolicoeur (2005) in a similar paradigm. A repeated measures analysis of variance (ANOVA) with distractor condition as a within-subjects factor confirmed that this difference in accuracy was reliable, $F(1, 15) = 17.21$, $p < .001$, $MSE = 43.21$.

————INSERT TABLE 1 and FIGURES 2 AND 3 ABOUT HERE————

Electrophysiological results

Contralateral-ipsilateral difference waveforms for each distractor condition are shown on the left side of Figure 2a. As predicted by the contingent capture hypothesis, *t*-tests versus zero revealed that a significant N2pc was generated in the target-colour distractor condition, *t*(15) = -2.54, *p* < .025, *SEM* = 0.213, but not in the nontarget-colour distractor condition, *t*(15) = 0.14, *p* > .89, *SEM* = 0.096, in a 185 ms to 280 ms time-window post distractor onset. Furthermore, the difference in mean amplitude between the two conditions was significant, as revealed by an ANOVA with distractor condition as a within-subjects factor, *F*(1, 15) = 6.47, *p* < .025, *MSE* = 0.3821. The ERP waveforms recorded at electrodes ipsilateral and contralateral to the target-coloured distractor, showing the N2pc effect together with the overlapping activity elicited by the RSVP stream are shown on the right side of Figure 2a. The ERP waveforms clearly show that the contralateral-ipsilateral difference wave arises from a relative amplitude difference and not from a change in the latency or morphology of the ERP waves. The scalp topography of the difference wave generated in the target-colour distractor condition is shown in Figure 3a. The present scalp distribution is very similar to that of N2pc distributions observed in previous studies that used visual displays comparable to ours (e.g., Brisson & Jolicoeur, 2007; Robitaille & Jolicoeur, 2006, 2007), supporting the interpretation of this effect as a shift of visuospatial attention.

Visual inspection of the subtraction curves also revealed a contralateral positivity in the time range of the P1 component. Using the same criteria as that used to define the N2pc measurement window, we analyzed the mean amplitude of the positivity in a time-window of 105 ms to 145 ms post distractor onset. This analysis revealed that the positivity was significant in the nontarget-colour distractor condition, $t(15) = 3.91$, $p < .001$, $SEM = 0.059$, but not in the target-colour distractor condition, $t(15) = 1.53$, $p > .14$, $SEM = 0.156$. However, the difference in mean amplitude between the two conditions was not significant, $F(1, 15) = 0.003$, $p > .95$, $MSE = 0.1715$. We explore the origin of this positive deflection in Experiments 4 and 5.

The N2pc results are consistent with visuospatial accounts of contingent attentional capture. The fact that an N2pc was observed following the presentation of an attention-capturing target-coloured distractor indicates that visuospatial attention was deployed to the position of this distractor. Furthermore, these results provide support of the contingent capture hypothesis of Folk et al. (1992) and against the brief attentional dwell time account of Theeuwes et al. (2000). In direct contradiction to the prediction derived from the brief attentional dwell time account, no N2pc wave was observed following nontarget-coloured distractors. This latter result was obtained despite the fact that the nontarget colours were equally salient as the target colour. Indeed, across subjects, they were exactly the same colours. However, an N2pc was found only when the coloured distractor matched the top-down control setting needed to select the target.

EXPERIMENT 2

In the previous experiment, the distractor was probably easy to discard as a potential target, because it was always a "#" symbol, whereas the participants were searching for a digit. Therefore, it is likely that, despite the ability of target-coloured distractor to capture attention, subjects could most likely avoid prolonged attention engagement and elaborate processing of the distractor. In Experiment 2, we introduced a category manipulation in order to influence the extent and duration of distractor processing. If, in addition to influencing what stimuli capture attention, top-down attentional control settings influence how stimuli are processed, it is possible that attentional engagement at the location of distractor stimuli may be enhanced for distractors that are similar to the target. Consequently, the magnitude or the duration of the N2pc elicited by distractors that match the target category may be enhanced relative to that elicited by distractors that do not match the target category.

METHODS

Stimuli and procedure

The stimuli and procedure used in Experiment 2 were the same as in Experiment 1 with the following exceptions. The task was either to identify a colour-defined target digit within a RSVP stream of coloured digits or to identify a colour-defined target letter within a stream of letters. Target category was counterbalanced across subjects. Digit streams consisted of the digits 2 through 9 and letter streams consisted of the capital letters A through H. The bilateral distractor pairs consisted of one grey nontarget-category item, digit or letter, and a contralateral coloured digit or letter. As in Experiment 1, the coloured distractor matched the target colour on 50% of trials. In addition, the character matched the target category, digit versus letter, on half of the trials. This gave rise to four distractor conditions, depicted in Figure 1b: target-category/target-colour, target-category/nontarget-colour, nontarget-category/target-colour, and nontarget-category/nontarget-colour. Each experimental session consisted of 20 practice trials followed by 1024 experimental trials, divided into eight blocks. Each block consisted of an equal number of trials for each distractor condition and coloured distractor side.

Subjects

Twenty one subjects participated in Experiment 2 (6 male, mean age: 21.1). Five subjects were excluded from data analysis. Four subjects were rejected because an excessive number of trials were rejected due to EEG or EOG artefacts and one due to poor behavioural performance (0.08% correct in one condition). The remaining 16 subjects (5 male) ranged had a mean age of 21.3 years. An average of 88.2% of the trials was included in the ERP analysis for these 16 subjects.

Results and Discussion

Behavioural results

Mean percentages of correct target identifications (Table 1b) were entered into a repeated measures ANOVA with distractor colour condition and distractor category condition as within-subjects factors. Again, a target-coloured distractor produced attentional capture (nontarget-coloured distractor: 75.9%, target-coloured distractor: 69.6%, $F(1, 15) = 7.89$, $p < .015$, $MSE = 80.82$) and there was also a small main effect of target-category (nontarget-category distractor: 73.7%, target-category distractor: 71.8%, $F(1, 15) = 5.47$, $p < .035$, $MSE = 10.47$). The interaction was not significant, $p > .79$.

Electrophysiological results

The ERP and N2pc subtraction curves are depicted in Figure 2b. Topographic maps of the N2pc effect are shown in Figure 3b. The N2pc was computed in a measurement window of 185 ms to 285 ms post distractor onset. Only the two target-colour distractor conditions generated significant N2pcs (target-colour/nontarget-category: $t(15) = -2.27$, $p < .04$, $SEM = 0.226$, target-colour/target-category: $t(15) = -3.44$, $p < .004$, $SEM = 0.267$), whereas the mean amplitude did not significantly differ from zero in the two nontarget-colour distractor conditions (nontarget-colour/nontarget-category: $t(15) = -0.46$, $p > .65$, $SEM = 0.082$, nontarget-colour/target-category: $t(15) = -1.13$, $p > .27$, $SEM = 0.124$). A repeated measures ANOVA with distractor colour and distractor category conditions as within-subjects factors revealed that the main effects of both distractor variables were significant, indicating that the N2pc to a target-colour distractor was larger than that to a nontarget-colour distractor, $F(1, 15) = 12.26$, $p < .0035$, $MSE = 0.5138$, and that the same was true for a target-category distractor relative to a nontarget-category distractor, $F(1, 15) = 5.53$, $p < .035$, $MSE = 0.1875$. Although the interaction was only marginally significant, $F(1, 15) = 3.75$, $p < .075$, $MSE = 0.09783$, pairwise comparisons showed that target-category distractors produced a larger N2pc only in the target-colour distractor condition, $F(1, 15) = 7.44$, $p < .016$, $MSE = 0.1774$, and not in the nontarget-colour distractor condition, $F(1, 15) = 0.79$, $p > .38$, $MSE = 0.1080$.

In addition, the ERP curves seemed to show that the target-colour/target-category distractor condition produced a longer lasting N2pc than the target-colour/nontarget-category distractor condition. In order to verify if this effect was significant, the offset latency of the N2pc in each condition was measured by taking the moment in time when the offset of the subtraction curve reached 0 µV. Analyses using the jackknife procedure (Ulrich & Miller, 2001) confirmed that the N2pc observed in the target-colour/target-category distractor condition had a longer duration than that observed in the target-colour/nontarget-category distractor condition, $F(1, 15) = 6.08$, $p < .03$.

The finding of a significant N2pc in only the two target-colour distractor conditions indicates that the contingent attentional capture of visuospatial attention only occurs when distractor items possess the target-defining property. That is to say, if participants were looking for a red digit among coloured digits, the relevant stimulus property was the colour (red), and not the category (digit), which was shared with nontarget items in the RSVP stream. Therefore, only red items in the periphery were able to generate involuntary shifts of visuospatial attention to the location they occupied. However, the fact that the N2pc to a target-coloured distractor was larger and lasted longer when the distractor also shared the target category than when it did not, suggests that once attention had been captured to the distractor location, it was harder to disengage and shift back to the central RSVP stream when the distractor shared non-target-defining features with the target. These results suggest that the observer’s goals and strategies not only affect which stimuli will capture visuospatial attention but also the extent and duration of visuospatial attentional processing.

As in Experiment 1, the subtraction waveforms showed some evidence of a positive component contralateral to the coloured distractor in the P1 time-range. However, mean amplitude in a 110 ms to 155 ms post distractor onset time-window was only significantly different from zero in the target-colour/nontarget-category distractor condition, $t(15) = 2.46$, $p < .03$, $SEM = 0.117$, and marginally significantly different from zero in the nontarget-colour/target-category distractor condition, $t(15) = 1.87$, $p < .09$, $SEM = 0.096$. The other two distractor conditions did not produce contralateral positivities that approached significance, and ANOVAs considering distractor colour and category conditions as within-subjects factors did not reveal any significant main effects or interactions, all *p*s > .20.

EXPERIMENT 3

In Experiments 1 and 2, the peripheral distractors always preceded the target by 117 ms. Hence, they conveyed information about when the target would be occurring. It is therefore possible that subjects used the distractor display as an alerting cue, making it task-relevant. However, even if the subjects did use the temporal information provided by the peripheral distractors, we argue that it would not explain either the behavioural pattern of contingent capture, or the N2pc observed following target-coloured distractors only. First, the alerting value of the distractor display is identical across distractor conditions, so it would not yield any differential effects, behavioural or electrophysiological, between conditions. Second, alerting by a visual cue has been found to be homogeneous across the visual field (Fernandez-Duque & Posner, 1997), so a shift of visuospatial attention related to alerting would not be expected. However, to rule out this possible account of our results definitively, Experiment 3 was designed to minimize the temporally predictive nature of the distractor display by using four distractor-target lags, ranging from 117 ms to 817 ms, and increasing the variability between the start of the RSVP stream and the presentation of the target. Thus, the onset of the distractors provided no specific information concerning the time at which the target would appear.

Another potential problem with Experiments 1 and 2 was that the distractor display was not always perfectly balanced in terms of stimulus colour. Target-coloured distractors were always unique in the distractor display. By contrast, nontarget-coloured distractors could share the colour of the central digit in approximately 25% of the trials because both colours were selected independently at random. On these trials the grey item may have attracted attention due to its status as a colour singleton. Consequently, any N2pc elicited by nontarget-coloured distractors would be attenuated due to a reverse effect on one quarter of the trials. On this account, the N2pc in the nontraget-coloured distractor condition should have been smaller than for target-coloured distractors, but not eliminated. However, it is possible that a small N2pc elicited by nontarget-coloured distractors may have gone undetected in the previous two experiments. To rule out this account, in the present experiment the colour of the central stream digit in the distractor display was chosen randomly with the additional restriction that it could not be grey or the same colour as the coloured distractor on that trial.

METHODS

Stimuli and procedure

The stimuli and procedure used in Experiment 3 were the same as in Experiment 1 with the following exceptions. The RSVP stream was comprised of 15 to 26 coloured digits. As in Experiment 1, the colour of each nontarget digit in the stream was selected at random from the three nontarget colours and grey, with the restriction that no two consecutive digits could be presented in the same colour. Furthermore, the colour of the digit presented in the distractor frame could not be grey, or the colour of the coloured distractor for that trial. This manipulation ensured that on each trial, both distractors were unique in colour. The target position in the stream was randomly selected from the serial positions 7 to 21. The target was always followed by at least two digits. The time of the presentation of the peripheral distractors relative to that of the target was also varied. They could be presented along with the frame preceding the target (distractor-target lag 1), or 3, 5 or 7 frames prior to the target (distractor-target lags 3, 5, and 7). Each experimental session consisted of 20 practice trials followed by 640 experimental trials, divided into five blocks. Each block consisted of an equal number of trials for each distractor condition and coloured distractor side.

Subjects

Twelve subjects participated in Experiment 3 (4 male, mean age: 21.3 years). One subject was excluded from data analysis, due to an excessive number of rejected trials and poor behavioural performance. The remaining 11 subjects (4 male) had a mean age of 21.4 years. An average of 92.7% of the trials was included in the behavioural and ERP analysis for these subjects.

Results and Discussion

Behavioural results

Mean percentages of correct target identifications were entered into a repeated measures ANOVA with distractor colour condition and distractor-target lag as within-subjects factors. The contingent capture effect on accuracy was again observed (Table 1c), the mean accuracy was higher in the nontarget-colour than in the target-colour distractor condition, $F(1, 10) = 7.50$, $p < .03$, $MSE = 32.5$. The main effect of lag did not approach significance, $F < 1$. However, a significant interaction was obtained between these factors, $F(1, 10) = 4.41$, $p < .02$, $MSE = 20.3$. Consistent with Leblanc and Jolicoeur (2005) the effect of target colour decreased with increasing distractor-target lag, pairwise comparisons showed that the effect of distractor colour was only significant at the shortest distractor-target lag, $F(1, 10) = 18.04$, $p < .01$, $MSE = 25.2$.

Electrophysiological results

The ERP and N2pc subtraction curves are shown in Figure 2c. A topographic map of the N2pc effects is shown in Figure 3c. Analysis of the N2pc in a 170 ms to 300 ms latency window replicated the results of the previous two experiments. Analysis of mean amplitude revealed that a significant N2pc was generated in the target-colour distractor condition, $t(10) = -2.63$, $p < .03$, $SEM = 0.204$, but not in the nontarget-colour distractor condition, $t(10) = 0.49$, $p > .63$, $SEM = 0.120$. Furthermore, the difference in mean amplitude between the two conditions was significant, $F(1, 10) = 6.82$, $p < .03$, $MSE = 0.286$. Experiment 3 therefore replicates the findings of Experiments 1 and 2 with a perfectly balanced distractor display and in a context where the distractors did not predict the time of target presentation, thus, providing further support for the contingent capture hypothesis of Folk et al. (1992), and for visuospatial accounts of contingent capture.

As in the previous two experiments, the subtraction waveforms showed some evidence of a positive component contralateral to the coloured distractor prior to the N2pc. However, analysis of the mean amplitude versus zero in a 114 ms to 136 ms latency window did not reveal a significant difference for either the target-colour distractor condition, $t(10) = 1.03$, $p > .30$, *SEM* = 0.181, or the nontarget-colour distractor condition, $t(10) = 0.01$, $p > .98$, *SEM* = 0.131. In addition, a second positivity was observed following the N2pc. Analysis of the mean amplitude in a 332 ms to 382 ms latency window again failed to reveal a significant effect for either the target-colour distractor condition, $t(10) = 1.77$, $p > .10$, *SEM* = 0.201, or the nontarget-colour distractor condition, $t(10) = 1.60$, $p > .13$, *SEM* = 0.156.

EXPERIMENT 4

Although the lateralized positive components found in the previous experiments do not seem to be reliably significant, we did observe them in three experiments, with different subjects and slightly different distractor conditions. In Experiments 4 and 5, we attempted to determine what experimental factors are responsible for this effect. In Experiment 1 through 3, the RSVP stream elicited a steady-state like modulation that corresponded to the presentation rate of items in the stream. The observed steady-state oscillation exhibited positive and negative peaks at latencies corresponding to those of the contralateral positivity and the early portion of the N2pc. Therefore, these effects could have arisen from an enhancement of the steady-state activity contralateral to the distractor. Such an effect could possibly arise from a rapid shift of visuospatial attention to the location of the coloured distractor that resulted in an amplification of the contralateral positive peak preceding the N2pc. In Experiment 4, we modified the design to eliminate the RSVP stream. If the positivity observed in Experiments 1, 2, and 3 does indeed reflect an enhancement of steady-state activity, it should not be present in Experiment 4.

METHODS

Stimuli and procedure

A schematic representation of the stimulus sequence used in Experiment 4 is depicted in Figure 1c. The stimuli and procedure used in Experiment 4 were the same as in the previous experiments with the following exceptions. The RSVP stream was replaced by the simultaneous presentation of three coloured digits presented on the vertical midline in the center of the display. Subjects were required to report the identity of a digit with the specified target colour within this display. Target colour was counterbalanced across subjects and the colour of nontarget digits was selected at random from the three nontarget colours. The target display was presented for 83 ms and the vertical position of the target digit was selected at random on each trial. The target display was immediately replaced by a mask display consisting of three grey “W” characters, presented for 117 ms at the locations where the three digits had appeared. On two thirds of trials a bilateral pair of distractors was presented prior to the target display. As in Experiment 1, the distractors were “#” signs, one grey and the other coloured. The distractor display was presented for 117 ms and there was no interstimulus interval between the distractor and target displays. The grey fixation cross remained in the center of the display at the time of presentation of the distractors. On half of the distractor-present trials the coloured distractor matched the target colour (target-colour condition) and on the remaining half it did not (nontarget-colour condition). Each experimental session consisted of 20 practice trials followed by 1008 experimental trials, divided into seven blocks. Each block consisted of an equal number of trials for each distractor condition and coloured distractor side.

Subjects

Twenty six subjects participated in Experiment 4 (6 male, mean age: 21.4). Eight subjects were excluded from data analysis. Seven subjects were rejected because an excessive number of EEG or EOG artefacts and one subject was rejected due to excessive residual horizontal EOG activity after artefact rejection. The remaining 18 subjects (4 male) had a mean age of 21.4 years. On average, 84.6% of the trials were included in the ERP analysis for these subjects.

Results and Discussion

Behavioural results

Mean percentage of correct target identifications are shown in Table 1d. The typical contingent capture effect was observed once again, as the subjects performed significantly worse in the target-colour distractor condition than in the nontarget-colour distractor or in the distractor-absent conditions, $F(2, 34) = 8.97$, $p < .001$, $MSE = 10.10$.

Electrophysiological results

The ERP and N2pc subtraction curves are depicted in Figure 2d. A topographic map of the N2pc effect is shown in Figure 3d. As in Experiments 1 and 3, a significant N2pc was generated in the target-colour distractor condition, $t(17) = -5.53$, $p < .001$, $SEM = 0.250$, but not in the nontarget-colour distractor condition, $t(17) = -0.70$, $p > .49$, $SEM = 0.122$, in a 195 ms to 250 ms time-window post distractor onset. Furthermore, the difference in mean amplitude between the two conditions was significant, $F(1, 17) = 25.11$, $p < .001$, $MSE = 0.6025$. We thus replicated, once again, the electrophysiological effect associated with contingent attentional capture showing that the presentation of a target-coloured distractor elicits a shift of visuospatial attention to the location it occupies, which is not the case for an equally-salient nontarget-coloured distractor. The main goal of this experiment was to see if removing the RSVP stream would eliminate the lateralized positivity observed in the first two experiments of the present study. On the contrary, Experiment 4 produced significant positivities in a 115 ms to 150 ms post distractor onset time-window in both the target-colour and nontarget-colour distractor conditions, $t(17) = 2.80$, $p < .015$, $SEM = 0.124$ and $t(17) = 4.17$, $p < .001$, $SEM = 0.138$, respectively. The difference in mean amplitude between the two distractor conditions in this time-window was not significant, $F(1, 17) = 2.35$, $p > .14$, $MSE = 0.1946$.

In addition, a second positive deflection could be seen in the subtraction waveforms in Experiment 4. This later, lateralized positivity was significantly different from zero in both target-colour and nontarget-colour distractor conditions, $t(17) = 2.87$, $p < .015$, $SEM = 0.165$, and $t(17) = 3.68$, $p < .002$, $SEM = 0.180$, respectively, but was not significantly different between the two distractor conditions, $F(1, 17) = 0.82$, $p > .37$, $MSE = 0.4046$.

In Experiment 4, the distractor display, consisting of one grey and one coloured distractor, was always presented together with a central grey fixation cross. Therefore, one might argue that the display was not perfectly balanced at the perceptual level, the coloured distractor being the only uniquely coloured item in the display. However, given the similar results obtained in Experiments 1, 2, and 3

(Experiments 1 and 2 exhibiting the same kind of imbalance, taken care of in Experiment 3), it is very unlikely that this would have affected the pattern of behavioural or electrophysiological results.

EXPERIMENT 5

Taken together, the results of Experiments 1, 2, 3, and 4 demonstrate that the contralateral positivity observed in the P1 time-range is not associated with a particular distractor condition or with the attentional control settings required to perform the task. Consequently, it is unlikely that this effect is related to either attention orienting or to the observed pattern of behavioural performance. In all four experiments, there were always one grey and one coloured distractor. Moreover, the coloured distractor was presented in the target colour more often (in half the trials) than in any of the three nontarget colours (present in one sixth of the trials each). Therefore, the positive component observed here could be linked to a contextual imbalance in the experimental design, regarding the relative frequency of presentation of each colour and grey in the periphery, even though each distractor display was balanced on the sensory level, every colour and grey being equiluminant. In Experiment 5, the two peripheral distractors were always coloured, and each colour was used equally often. If the observed lateralized positivity was due to an imbalance in the distractor display in terms of frequency of the colours presented, it should not be observed in Experiment 5.

METHODS

Stimuli and procedure

The stimuli and procedure used in Experiment 5 were the same as in Experiment 4 with the following exceptions. The distractor display always consisted of two coloured distractors. In the target-colour condition (half of the distractor-present trials), one distractor matched the target colour and the other was in a colour selected from the three nontarget colours, and in the nontarget-colour condition (the remaining half of the distractor-present trials), both distractor colours were selected from the three nontarget colours, with the constraint that they were never the same colour. Each of the four colours was attributed to a peripheral distractor equally often. Each experimental session consisted of 20 practice trials followed by 864 experimental trials, divided into six blocks. Each block consisted of an equal number of trials for each distractor condition and coloured distractor side.

Subjects

Thirty four subjects took part in Experiment 5 (12 male, mean age: 21.2). Ten subjects were excluded from data analysis. Four subjects were rejected because an excessive number of EEG or EOG artefacts and six subjects were rejected due to excessive residual horizontal EOG activity after artefact rejection. The remaining 24 subjects (10 male) had a mean age of 21.4 years. On average, 85.0% of the trials were included in the ERP analysis for these subjects.

RESULTS AND DISCUSSION

Behavioural results

Experiment 5 replicated the contingent capture effect observed in Experiment 4, with mean accuracy (Table 1e) in the target-colour distractor condition that was lower than in both the nontarget-colour distractor and the distractor-absent conditions, $F(2, 46) = 18.40$, $p < .0001$, $MSE = 9.13$.

Electrophysiological results

The ERP and N2pc subtraction curves for the target-coloured distractors are depicted in Figure 2e. A topographic map of the N2pc effect is shown in Figure 3e. A subtraction curve was computed only for the target-colour distractor condition, because in the nontarget-colour distractor condition, colours were assigned randomly to each distractor, therefore, computing a subtraction curve in this condition would not be informative. Once again, the N2pc results suggested that contingent attentional capture is associated with a shift of visuospatial attention to the location of the distractor. Using a time-window of 205 ms to 255 ms post distractor onset, we found a significant N2pc in the target-colour distractor condition, $t(23) = -4.57$, $p < .001$, $SEM = 0.136$.

The lateralized positivity observed in the first three experiments of the present study was completely absent in Experiment 5. In the 115 ms to 150 ms post distractor onset time-window which was used to calculate this positivity in Experiment 4, the subtraction waveform of Experiment 5 was found to be significantly more negative than zero, $t(23) = -2.09$, $p < .05$, $SEM = 0.082$. The absence of such a lateralized positivity in a paradigm where the peripheral stimuli were not only balanced on the sensory level, but also on the contextual level, with each colour presented equally often in the periphery, suggests that the positivity is more likely to be due to perceptual rather than attentional effects. The later positivity seen in Experiment 4 was apparent in the subtraction curve from Experiment 5 as well, but did not reach significance, $t(23) = 1.59$, $p < .13$, $SEM = 0.176$.

General Discussion

The primary objective of the present study was to test the competing accounts of contingent capture effects proposed by Folk et al. (1994) and Theeuwes et al. (2000). To achieve this goal, we utilized the N2pc component of the visual ERP to track the allocation of visuospatial attention after the presentation of peripheral distractors that either shared or did not share the target-defining selection feature. In all five of the current experiments, the target was a colour-defined item embedded in a RSVP stream or spatial search array of heterogeneously coloured items. Target items were preceded by distractor displays comprised of two equiluminant items presented in the periphery of the visual field. Thus, our distractor displays consisted of stimuli that were balanced at the sensory level, and the only differences between items in the left and right visual fields were defined according to the attentional goals of the observer. Between-subjects counterbalancing ensured that any small residual differences in bottom-up salience across the colours could not have produced the observed behavioural and electrophysiological results.

The results of all five experiments were consistent and unequivocal. Target-coloured distractors elicited significant N2pc waves, indicating that visuospatial attention had been drawn to their location. In contrast, nontarget-coloured distractors did not generate N2pc waves, suggesting that participants were able to ignore them and remain focused on the central search array. These electrophysiological findings parallel the behavioural effects. Target identification accuracy was better when targets were preceded by nontarget-coloured distractors than when they were preceded by target-coloured distractors. Furthermore, in Experiments 4 and 5, accuracy was no worse in the nontarget-colour distractor conditions than in a distractor absent condition in which there were no distractors at all, replicating the finding of Folk et al. (2002). Taken together, these results provide strong evidence against the brief attentional dwell time account of capture proposed by Theeuwes et al. (2000). In contrast, the current results are completely consistent with contingent capture hypothesis of Folk et al. (1992).

A secondary objective of the current study was to study the effect of target-distractor similarity on distractor processing. Recently, Ghorashi and colleagues (2003) demonstrated that irrelevant distractors that possessed the target-defining attributes slowed target identification reaction time when presented prior to the target within the focus of attention. This result indicates that the time required to shift attention towards and away from attention capturing distractors is not the only source of processing interference underlying contingent capture and that the time taken to process the distractor also plays a role. In order to account for their results, Ghorashi et al. proposed a two-stage model to explain contingent capture, the *contingent processing hypothesis,* arguing that the visuospatial interpretation was not sufficient to account for the temporal deficit in the response to a target preceded by an attention-capturing distractor. In their view, items are first submitted to an input-filtering stage that determines if they match the observer's attentional settings. If it is found that they do, they move on to a capacity-limited processing stage in which stimuli are processed serially. Hence, if a distractor sharing the target feature is presented before the target, it will gain access to this second processing stage, preventing or delaying the processing of the target itself and causing longer response times and/or lower accuracy (e.g., if masked).

We investigated the effect of distractor processing in Experiment 2 by manipulating the extent to which targets and distractors shared features. In addition to our standard colour manipulation, we added a category manipulation. A distractor could share the target colour, the target category, both attributes, or neither attribute. According to Ghorashi et al.'s (2003) model, a distractor is processed as though it were a target if it matches the observer's attentional control setting. Given this, one would expect that distractors that are similar to the target and allow for similar processing will receive more extensive processing than dissimilar distractors that can be quickly discounted. Therefore, we hypothesised that a distractor sharing both the target colour and category would result in a larger or longer-lasting capture effect. In accordance with this prediction, we found that both distractor colour and distractor category affected response accuracy, with accuracy rates being the lowest when the distractor shared both attributes with the target. In addition, an N2pc was generated only by target-coloured distractors, showing that only distractors that shared the target-defining selection feature — and not just any target feature — triggered an involuntary shift of attention to their location. Furthermore, when the distractor shared the target category in addition to the target colour, the N2pc was larger and offset later than when it shared only the target colour. This effect suggests that once attention has been attracted to the distractor location, if the distractor shared the category attribute with the target, it was more likely to be processed further, thus prolonging the engagement of visuospatial attention at this location. When the distractor did not share the target category, however, attention could be disengaged more easily from the distractor location and returned to the central search array more quickly. Therefore, the current results indicate that distractor processing can play a part in contingent capture, as suggested by Ghorashi et al. (2003), and that distractor processing extends the duration of the allocation of visuospatial attention to the location of the distractor.

Taken together, the current results and those of Hickey et al. (2006) provide strong evidence that contingent capture and capture by highly salient task-irrelevant singletons share similar underlying mechanisms, even though they occur under different attentional conditions. Hickey et al.'s study provided convincing evidence that highly salient singleton colour distractors trigger shifts of attention to their location when observers are searching for a less salient singleton shape target (thus adopting a singleton search mode) by showing that such distractors generated an N2pc component. In the present study, we show that the same mechanism seems to come into play when attention is captured in a contingent manner, by a distractor that is not particularly salient on the sensory level (at least not more salient than other distractors that do not capture attention), but that is unique in that it corresponds to the observer’s attentional set (requiring feature search mode).

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AUTHOR NOTES

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TABLE 1

Mean Accuracy in Target Identification by Distractor Condition

	Mean Accuracy % (SD)		
Distractor Condition:	Nontarget-colour	Target-colour	
(A) Experiment 1	74.5 (14.5)	64.9 (16.7)	
(B) Experiment 2			
Nontarget-category	76.7 (12.0)	70.6 (10.6)	
Target-category	75.0 (12.8)	68.5 (11.3)	
(C) Experiment 3			
Lag 1	78.2(17.6)	69.1(14.9)	
Lag 3	75.4(17.0)	72.4(15.8)	
Lag 5	73.7(17.9)	73.7(20.1)	
Lag 7	74.1(19.0)	72.9(20.4)	
Distractor Condition:	Absent	Nontarget-colour	Target-colour
(D) Experiment 4	93.0 (6.4)	93.5 (7.1)	89.4 (9.9)
(E) Experiment 5	88.9 (9.9)	89.5 (9.2)	84.6 (11.5)

FIGURE CAPTIONS

Figure 1. Illustration of the sequence of events in Experiments 1 (Panel A), 2 (Panel B), and 4 (Panel C). Outlined characters represent the target colour, black characters were nontarget colours, and grey characters were grey.

Figure 2. ERP subtraction waveforms for each distractor condition (left side) and raw ERP waveforms ipsilateral and contralateral to target-coloured distractors (right side) in Experiments 1 (Panel A), 2 (Panel B), 3 (Panel C), 4 (Panel D), and 5 (Panel E).

Figure 3. Topographical mapping of the N2pc in Experiments 1 (Panel A), 2 (Panel B), 3 (Panel C), 4 (Panel D), and 5 (Panel E). Maps were generated by computing the contralateral minus ipsilateral difference wave for each electrode pair and the mean amplitude in the measurement window used when analysing N2pc effects was calculated for each N2pc wave. The obtained values were mirrored across the midline, and the values for the midline electrodes were set to zero. The spherical splines interpolation technique was then used to estimate the topographic voltage distribution.

FIGURE 1

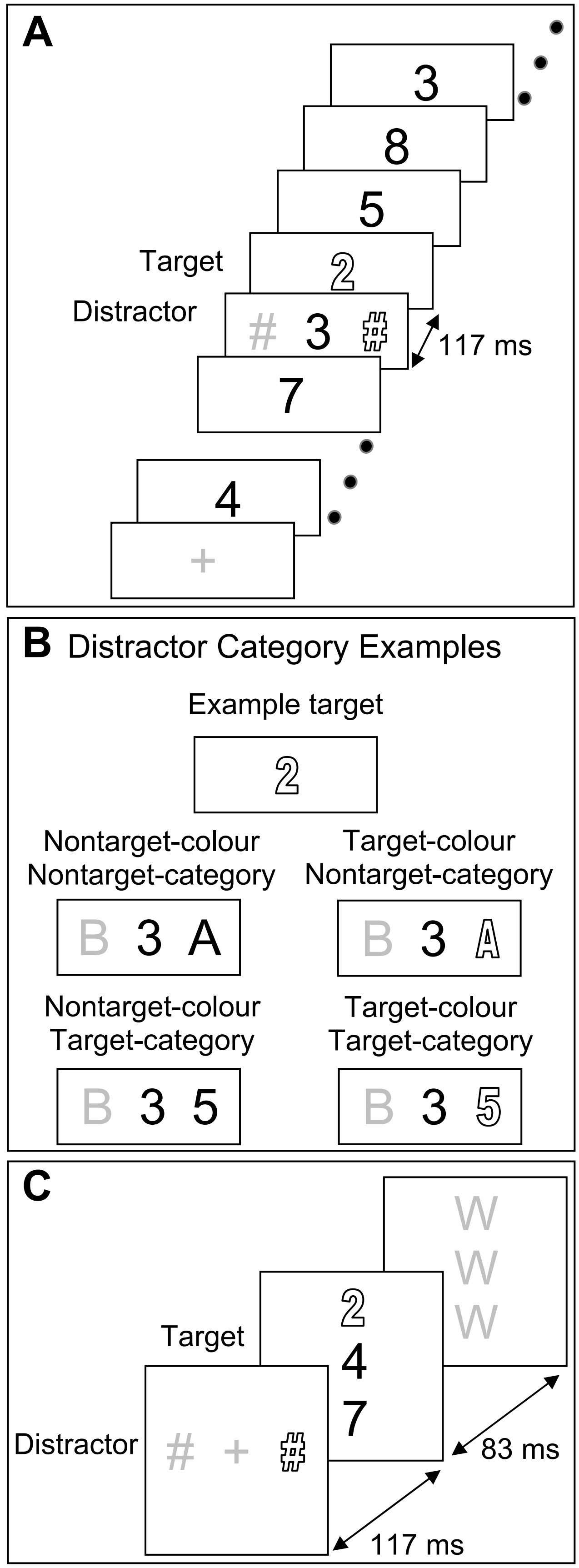

A
3
8
5
Target
2
Distractor
3
117 ms
7
4
+
B Distractor Category Examples
Example target
2
Nontarget-colour
Nontarget-category
B 3 A
Target-colour
Nontarget-category
B 3 A
Nontarget-colour
Target-category
B 3 5
Target-colour
Target-category
B 3 5
C
W
W
W
Target
2
4
7
Distractor
+
83 ms
117 ms

FIGURE 2

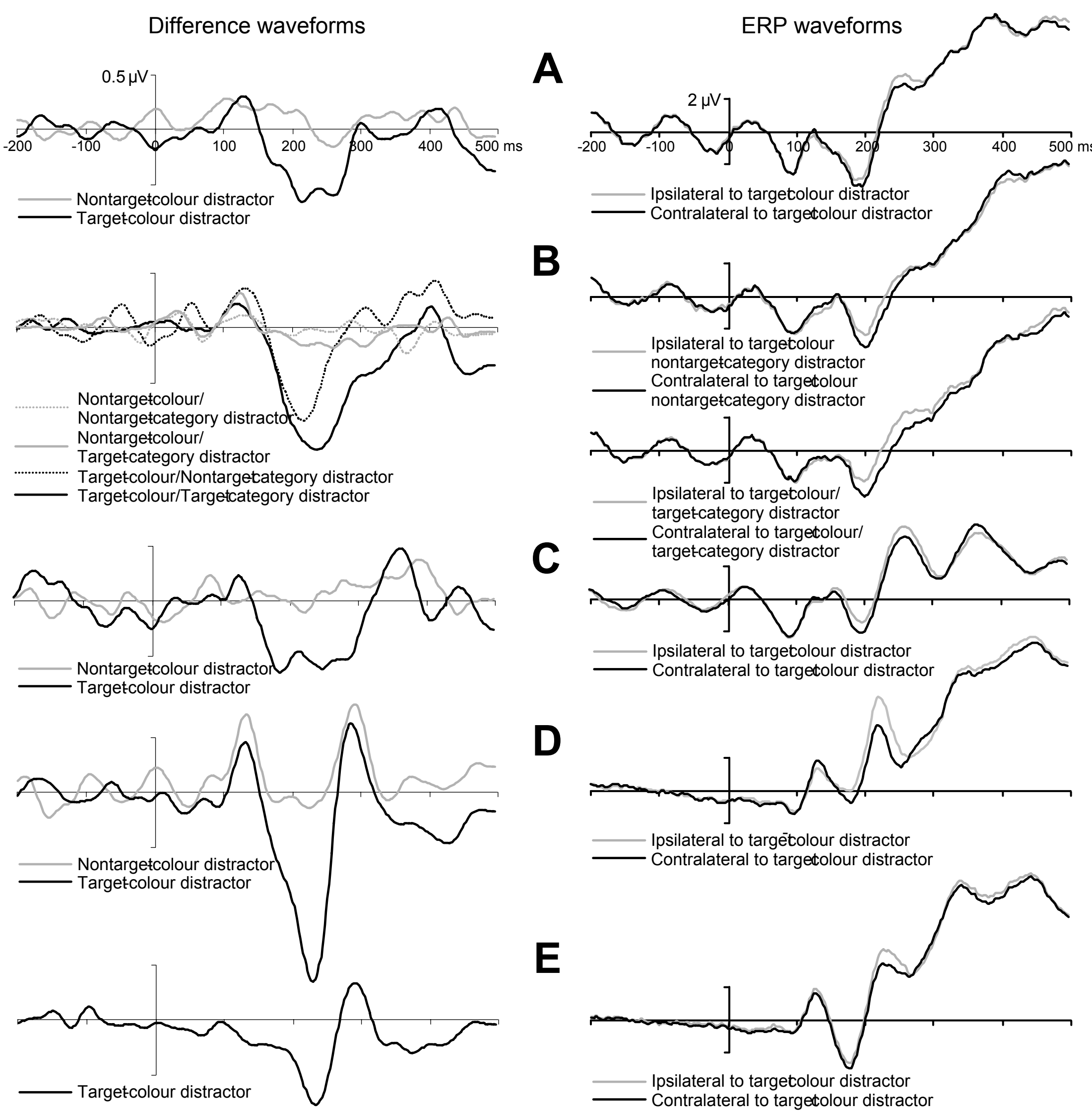
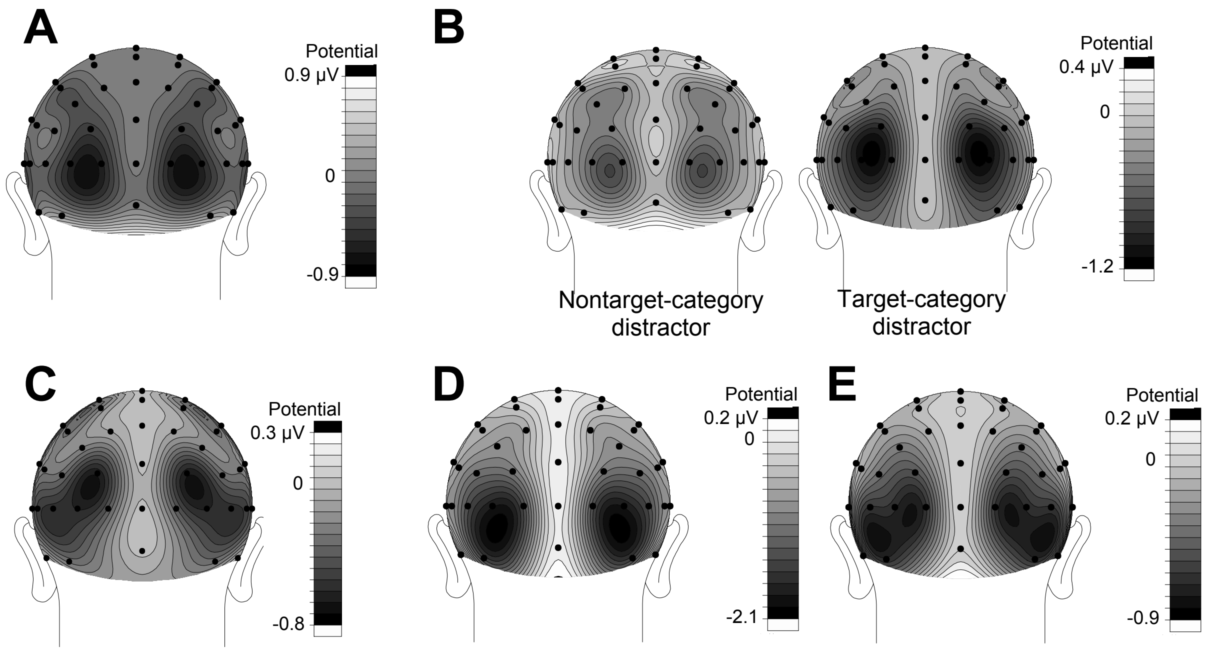

Difference waveforms
ERP waveforms
A
B
C
D
E
0.5 µV
2 µV
-200
-100
0
100
200
300
400
500 ms
Nontarget-colour distractor
Target-colour distractor
Ipsilateral to target-colour distractor
Contralateral to target-colour distractor
Nontarget-colour/
Nontarget-category distractor
Nontarget-colour/
Target-category distractor
Target-colour/Nontarget-category distractor
Target-colour/Target-category distractor
Ipsilateral to target-colour
nontarget-category distractor
Contralateral to target-colour
nontarget-category distractor
Ipsilateral to target-colour/
target-category distractor
Contralateral to target-colour/
target-category distractor

FIGURE 3


A
Potential
0.9 μV
0
-0.9
B
Potential
0.4 μV
0
-1.2
Nontarget-category distractor
Target-category distractor
C
Potential
0.3 μV
0
-0.8
D
Potential
0.2 μV
0
-2.1
E
Potential
0.2 μV
0
-0.9

ARTICLE 3 : YOU SEE WHAT YOU WANT TO SEE: ATTENTIONAL CAPTURE CONTINGENT ON ALPHANUMERIC CATEGORY

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É.L. & P.J. : Conception du projet et interprétation des résultats.

É.L. : Programmation des expériences, analyse des données et rédaction l'article.

P.J. : Révision du manuscrit

ABSTRACT

The guidance of attention to locations containing relevant information is crucial for efficient functioning. Research on contingent attentional capture has shown that bottom-up and top-down processes can interact to achieve this goal, at least for low-level visual features, such as colour, motion, and sudden onset. In these cases, visuospatial attention is deployed involuntarily to the location of items matching target-defining features. In the present study, we asked if more complex attributes could guide attention in that manner, as “targets” in the real world are rarely defined exclusively by their low-level features. Behavioural and electrophysiological results led to the conclusion that an attentional set in favour of a conceptual attribute, namely, alphanumeric category, can be successfully implemented, leading to contingent capture of spatial attention by distractors sharing the target’s category membership.

Introduction

We live in a world very rich in stimulation and information, so much so that one often cannot fully process all the information available at any given time. Therefore, it is imperative to select a part of this information to attend and process in detail. And it is better still if the selected information turns out to be relevant, that is to say that the observer will be able to use it to guide his behaviour properly according to current goals. Attention is thought to be directed by two broad types of mechanisms: ascending, or bottom-up processes, cause attention to be captured by sufficiently intense or salient stimuli, while descending, or top-down processes rely on behavioural goals to guide attention voluntarily. These two classes of processes can interact, as suggested by the contingent involuntary orienting hypothesis (Folk, Remington, & Johnston, 1992, but see Theeuwes, Atchley, & Kramer, 2000, for a competing account of attentional capture, based on stimulus salience). According to this hypothesis, a stimulus can capture attention involuntarily if it shares an attribute that is relevant for the task at hand, even if this particular stimulus is irrelevant (for a review of attentional capture and contingent attentional capture, see Pashler, Johnston, & Ruthruff, 2001). In that case, it is postulated that the observer establishes an attentional set in favour of the target item. While this is a voluntary process, once the attentional set is in place, stimuli corresponding to this set capture attention involuntarily (Folk et al., 1992; Folk, Remington, & Johnston, 1993).

According to different authors, the way the attentional set is implemented can take different forms. One account of contingent capture involves the content of working memory (Desimone & Duncan, 1995; Downing, 2000; Lien, Ruthruff, Goodin, & Remington, 2008; Pratt & Hommel, 2003). According to this interpretation, the observer encodes a whole target object in working memory, not only a target feature (Desimone & Duncan, 1995; Pratt & Hommel, 2003). Hence, any item matching the target object on any dimension (e.g., its form or its colour), not only on the relevant dimension (e.g., its colour), will capture attention. Pratt and Hommel (2003) refer to this interpretation as the memory-match hypothesis.

Di Lollo, Kawahara, Zuvic, and Visser (2001) have proposed the input-filtering hypothesis, which states that top-down processes are used to establish a dynamic filter incorporating the target-relevant feature(s), in order to configure the system so that it can process the target most efficiently. All incoming stimuli will then be processed through this filter; those that correspond to the filter settings will immediately be processed efficiently; those that do not share the relevant attribute(s) will either be processed inefficiently (with the system ill-configured), or will be stored in memory while the system is reconfigured to accommodate the processing of such items. Hence, in a contingent capture paradigm, a distractor that shares a relevant attribute with the target captures attention because it fits the input filter criteria and can be processed efficiently. This account admits that input filters can be configured to accommodate complex objects, such as letters and 3-D objects, and even conjunctions of features, given enough practice with the particular target stimuli. Therefore, it is possible that a whole object, or multiple properties of an object, can be implemented in one input-filter, as postulated by the memory-match hypothesis.

Contingent attentional capture has been reported for simple features such as sudden onset, colour, and movement (e.g., Folk, Remington, & Wright, 1994). However, one can ask, given the complexity of the natural environment, can an attentional set be implemented in favour of more complex stimuli? Can capture be contingent on more complex properties? In the present study, our goal was to test if capture could be contingent on alphanumeric category.

In a review intending to identify attributes that have the ability to guide visual attention, Wolfe and Horowitz (2004) classify alphanumeric category as a “doubtful case,” and claim that the answer resides in the ability or inability of overlearned sets of stimuli to guide attention. Although the input-filtering hypothesis put forward by Di Lollo and colleagues (2001) focuses on the physical features of the target template, it is plausible that such a model could incorporate connections with conceptual representations of complex sets of stimuli, such as extensively rehearsed categorial classifications. In accord with this hypothesis, multiple visual search studies have shown alphanumeric category effects, that is to say, more efficient search when the target and distractor items belonged to different categories (e.g., a target letter embedded in an array of digits) than when they belonged to the same category (e.g., a target letter amongst target distractors) (Brand, 1971; Dixon & Shedden, 1987; Gleitman & Jonides, 1976, 1978; Ingling, 1972; Jonides & Gleitman, 1972, 1976; Polk & Farah, 1998). Using an attentional blink paradigm, Dux and Coltheart (2005) also found greater interference when target letters were masked by letter distractors than by digit distractors.

Although these results argue in favour of the ability of a conceptual attribute, that is to say, alphanumeric category, to guide attention, they are disputed because alphanumeric category on the conceptual level might be confounded with differences in physical attributes between digits and letters. Deutsch (1977) argued against this account, stating that it is unlikely that there is a set of distinct features shared in common by all digits which is different from the set of letter-defining features shared by all letters, because of the seemingly arbitrary division of shapes into digits and letters, and because some digits are identical to some letters. Conversely, Cardosi (1986) argued that "attempts to list the features that distinguish uppercase letters from digits may be futile, if not misguided" (p. 327), first, because even if such a set of distinctive features could be identified, it would change with the typefaces used, and second, because such familiar patterns as digits and letters are probably processed globally. On the other hand, she suggests that a measure of overall similarity between digits and letters, without regard to features, may be relevant. Candidate general differences that distinguish letters and digits include a fixed width for digits (except for the narrower digit “1”), while letters vary in width, and the fact that curves in letters generally flatten on the top and bottom, contrary to the curves in digits. These differences could be attributed to the Arabic origin of digits and the Western origin of letters.

A number of strategies have been used to evaluate the contribution of physical characteristics in the alphanumeric category effect, with mixed results. The “oh-zero” effect is probably the best known of them. It refers to the finding that the same stimulus, “O,” allows more efficient visual search when presented amongst digits if it is introduced to the participants as the letter “oh,” but is found more efficiently when it is embedded in an array of letters if the participants are instructed to search for the digit “zero” (Gleitman & Jonides, 1976, Experiment 1; Jonides & Gleitman, 1972; see also Dux & Coltheart, 2005, for a similar manipulation). However, Duncan (1983) failed to replicate this finding (see also Cardosi, 1986, Experiment 2). Other studies attempted to equate physical similarity intra- and inter-category, either by pairing digits and letters according to their physical resemblance or by using a special font; some did find a reliable category effect (Dixon & Shedden, 1987, Experiment 2; Ingling, 1972), while others failed to (Cardosi, 1986, Experiments 1 & 2; Krueger, 1984).

If behavioural studies yield inconclusive results, further support for the alphanumeric category effect comes from functional neuroimaging studies and neural network simulations. While “nobody believes that nature has equipped us with parallel processors for the Roman alphabet” (Wolfe & Horowitz, 2004, p. 6), it seems that extensive experience with this class of stimuli may have resulted in the development of a cortical area specialized in letter processing, and probably, though to a much lesser extent, in digit processing (Baker et al., 2007; Polk & Farah, 1998; Polk et al., 2002). According to Polk and colleagues (Polk & Farah, 1998; Polk et al., 2002), this can be explained by the frequent occurrence of letters (and digits, to a lesser degree) and by their pattern of co-occurrence in the environment, and by the correlation-based learning that takes place in the brain. In fact, a neural network learning through hebbian rules and stimulated by letters and digits in a way that simulates a real reader’s experience produced letter and digit areas comparable to what was observed in a neuroimaging study (Polk & Farah, 1998). Furthermore, this model accurately predicts a reduced category effect in people exposed to unusual patterns of co-occurrence of digits and letters: Canadian postal workers, who frequently have to process Canadian postal codes composed of mixed strings of digits and letters (e.g., J3V 5N8), not commonly encountered in a typical reader’s experience, display a smaller category effect, probably because their digit and letter representations are less segregated than in typical readers (Polk & Farah, 1998).

Taken together, results of studies on the processing alphanumeric category suggest that it can be accessed very efficiently, such that a character suffers less interference from characters from the opposite category than from the same category. Therefore, we hypothesized that it would be possible to establish an efficient attentional set in favour of a particular alphanumeric category, leading to involuntary contingent capture of attention by distractors sharing this categorial membership. Experiment 1 of the present study tested this hypothesis. We modified the paradigm used by Leblanc and Jolicoeur (2005), so that the target defining attribute was now categorial membership. Participants were presented with a rapidly changing sequence of digits, in which a single letter was embedded, and their task was to report the identity of this target letter (target and distractor categories were counterbalanced between subjects). To induce attentional capture, two peripheral distractors appeared at various distractors-target stimulus onset asynchronies (SOAs) prior to the target. Those peripheral distractors could be symbols, or characters that shared or did not share the target's category membership. If it is the case that an attentional set can favour one alphanumeric category over the other, than we should observe a drop in accuracy in the report of the target's identity only when a target-category distractor is presented shortly before the target, even if the participants have no incentive to attend to peripheral distractors. This is indeed what was found.

However, given the complexity of the capturing property, alphanumeric category, one can ask if the same mechanisms that underlie contingent capture by simple features are also at work in the present experiment.

Converging evidence has shown that contingent capture by simple features such as sudden onset and colour consists in a shift of visuospatial attention to the location of the capturing distractor. In contingent capture studies using cueing paradigms, interactions between the capturing distractor location and the target location are observed, such that responses are facilitated when the target follows the distractor in the same location, and impaired when the target appears in a different location (Folk & Remington, 1998; Folk et al., 1992). Also using a cueing paradigm, Remington, Folk, and McLean (2001) observed compatibility effects between the identities of the distractor presented at the location of the capturing cue and that of the target. Moreover, Serences and colleagues (2005) used functional magnetic resonance imaging (fMRI) to examine brain activity during a contingent attentional capture task and revealed that brain areas associated with the control of visuospatial attention were more active in response to distractors sharing the target-defining colour than to nontarget-coloured distractors.

Even more convincing data in favour of the visuospatial interpretation of contingent capture comes from ERP studies measuring the N2pc to capturing distractors. Compared to behavioural and imaging data, ERPs are advantageous because they allow a relatively direct and continuous monitoring of the processing of items to which no response is made, such as distractors in attentional capture paradigms, with excellent temporal resolution (Luck, 2005).

The N2pc is an ERP component thought to reflect the locus of visuospatial attention, or more specifically, spatially selective processing following a shift of visuospatial attention (Kiss, Van Velzen, & Eimer, 2008). It is usually observed between 170 and 280 ms post stimulus onset (in the time-range of the N2), and consists of a greater negativity at posterior electrode sites contralateral, relative to ipsilateral, to the attended location (Luck & Hillyard, 1994). It is this contingency with the location of the attended stimulus, and the fact that it seems to originate from parietal and occipito-temporal areas, known to be involved in the implementation of attentional selection (Hopf et al., 2000), that link the N2pc to visuospatial attention. Moreover, the N2pc is larger in situations that require a greater contribution of focal attention, such as when the task requires a complex discrimination process (Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994), when the target is surrounded by numerous distractors (Luck et al., 1997) or when distractors are less easily differentiated from the target (Luck & Hillyard, 1994). Although it has been suggested that the N2pc reflects distractor suppression (Luck, 1995; Luck et al., 1997; Luck & Hillyard, 1994), recent evidence seems to favour an interpretation highlighting target enhancement as the main process behind the N2pc (Brisson & Jolicoeur, 2007; Eimer, 1996; Eimer & Kiss, 2008; Hickey, Di Lollo, & McDonald, 2008).

Recently, several studies have found that stimuli eliciting contingent capture, that is to say, irrelevant items that possess a target-defining attribute, generate an N2pc (Brisson, Leblanc, & Jolicoeur, 2009; Eimer & Kiss, 2008; Kiss, Jolicoeur, Dell'Acqua, & Eimer, 2008; Leblanc, Prime, & Jolicoeur, 2008; Lien et al., 2008), corroborating the hypothesis that they draw visuospatial attention to their location and receive spatially selective processing. Salient distractors capturing attention in a bottom-up fashion also seem to generate an N2pc (Hickey, McDonald, & Theeuwes, 2006).

However, there are still non-spatial sources of interference that can contribute to create behavioural effects that can be interpreted as contingent capture. For instance, Ghorashi, Zuvic, Visser, and Di Lollo (2003) showed that the time taken to process the distractor also plays a role in contingent capture, by presenting an irrelevant distractor that possessed the target-defining attributes prior to the target and within the focus of attention, such that no shift of visuospatial attention to and from the distractor location was possible. This interpretation was supported by Leblanc et al. (2008), in a paradigm that also involved a shift of visuospatial attention to the distractor location. They found that when participants were searching for a target-coloured digit embedded in a series of coloured digits in rapid serial visual presentation (RSVP), attention was captured by target-coloured peripheral distractors exclusively, as evidenced by lower accuracy and the presence of an N2pc on trials when a target-colour distractor was present. More importantly, this capture effect was larger if the target-coloured distractor was also a digit, relative to a symbol (#) or a letter: the results showed even lower accuracy and a longer-lasting N2pc on these trials, suggesting that the observer's goals and strategies not only affect which stimuli capture visuospatial attention, but also the extent and duration of visuospatial attentional processing. Hence, the more similar the distractor is to the target, the more processing it receives, and the more the performance to the target is affected.

Similarly, the processes at work in the category effect might operate at several levels. Some results point to a spatial interpretation as is the case in contingent capture: in between-category visual search, the location containing the item of the target category seems to be "tagged" for further processing such as identification (Jonides & Gleitman, 1976; Cardosi, 1986, Experiment 3). However, this finding has been attributed to the physical differences of the target-category item with the field items belonging to the opposite category, rather than to the categorial membership *per se* (Cardosi, 1986). Other authors postulate that the segregation between items of both categories takes place at later stages, such as encoding in memory and activation of motor responses (Deutsch, 1977), or access to identity and category codes when the time comes to compare the target representation with the display items (Gleitman & Jonides, 1978).

Therefore, in Experiment 2 and 3, we replicated the main conditions of Experiment 1 while recording ERPs. We specifically looked for the presence of an N2pc to target-category distractors, in order to distinguish between spatial and non-spatial accounts of contingent capture by alphanumeric category. In Experiment 4, we replicated our findings with a set of stimuli that allowed us to control for the differences in physical features between letters and digits.

EXPERIMENT 1

METHODS

Stimuli and procedure

The sequence of events of a trial is depicted in Figure 1. The task was to report a single target defined by category membership (digit or letter) embedded in a series of characters of the opposite category in RSVP at the center of a black screen, which participants viewed from a distance of approximately 57 cm. Each item was present on the screen for 117 ms, with no blank inter stimulus interval. The digit set was comprised of the digits 2 to 9, and the letter set, of the letters A, B, C, D, E, F, G, and H. The target and distractor categories remained the same throughout the entire experimental session for each participant, and were counterbalanced between participants. All characters were grey and measured 1.3° of visual angle in height. A fixation cross was presented at the beginning of each trial, and was replaced by the RSVP sequence when the participant initiated the trial by a press of the spacebar. The sequence at fixation contained only one item of the target category, and the participant was instructed to report the identity of this target when prompted at the end of the trial, without speed pressure. The nontarget items in the RSVP stream were determined randomly, with the restriction that the same character could not be presented in two consecutive frames. The numeric key pad of the computer keyboard was used to record the participants' responses. For the participants searching for letter targets, the keys 2 to 9 were assigned the letter values A to H. Paper labels were placed on top of the keys to help the participants identify each key.

————INSERT FIGURE 1 ABOUT HERE————

To test for attentional capture, two distractor items were presented 2° left and right of the RSVP stream (measured center-to-center), either at the time of target presentation or at the time of presentation of one of the eight previous RSVP frames, resulting in distractor-target stimulus onset asynchronies (SOAs) of 0 to 933 ms. Five distractor conditions were used: distractors absent (A); two symbol (#)

distractors (S); one symbol and one nontarget-category distractor (N); one symbol and one target-category distractor (T); and one target-category distractor and one nontarget-category distractor (T-N). Participants were specifically told to ignore the peripheral distractors, as the target would always be presented within the central RSVP stream. Thus, any allocation of attention to the peripheral distractors was considered as involuntary. The side of presentation (left or right) of each distractor was chosen at random on each trial. When character distractors were present (letter or digit), their identity was chosen at random with the restriction that it could not be the same as the target for that trial. All SOAs and distractor conditions were presented equally often and intermixed within blocks of trials. Each participant completed 30 practice trials, followed by three blocks of 120 trials, totalling 360 experimental trials.

Participants

Sixteen volunteer subjects (3 men, mean age = 21.3) participated in this experiment in exchange for financial compensation. All subjects reported having normal or corrected-to-normal vision.

RESULTS AND DISCUSSION

The mean percentages of correct target identifications for each target category, distractor and SOA condition are listed in Table 1. These data were subjected to a repeated-measures ANOVA with target category (Letter, Digit) as a between-subjects factor and with distractor condition (A, S, N, T, and T-N) and SOA (0 to 933 ms) as within-subjects factors. Accuracy was significantly higher when the target was a digit than when it was a letter (94.6 and 87.8% correct, respectively), as revealed by the target category main effect ($F(1, 14) = 5.88$, $MSE = 14.09$, $p < .03$, $\eta_p^2 = 0.30$). The main effect of distractor condition was also significant ($F(4, 56) = 10.06$, $MSE = 352.00$, $p < .001$, $\eta_p^2 = 0.42$), with lower accuracy in the T and T-N distractor conditions (86.2 and 85.3% correct, respectively) than in the A, S, and N distractor conditions (95.4, 94.9, and 94.0% correct, respectively). The interaction between target category and distractor condition was significant as well ($F(4, 56) = 2.87$, $MSE = 352.00$, $p < .04$, $\eta_p^2 = 0.17$). This interaction was driven by the fact that the amplitude of the effect of distractor condition on accuracy was smaller in the Digit target category condition than in the Letter target category condition. However, the main effect of distractor condition was significant in both target category conditions (Digit target category condition: $F(4, 28) = 5.28$, $MSE = 78.05$, $p < .003$, $\eta_p^2 = 0.43$; Letter target category condition: $F(4, 28) = 6.62$, $MSE = 626.00$, $p < .001$, $\eta_p^2 = 0.49$). The smaller amplitude of the effect in the Digit target category condition was most likely due to a ceiling effect in this condition, possibly because the response mapping was more familiar (participants had to enter their responses using the numeric key pad of the computer keyboard). In fact, in the Digit target category condition, accuracy was 100% correct in 239 (66.4%) of the 360 cells (each cell resulting from the averaging of eight trials) generated by the 8 (participants) X 5 (distractor conditions) X 9 (SOAs) analysis, compared to 171 cells (47.5%) in the Letter target category condition. Therefore, this factor is not considered in further analyses. The SOA factor did not yield any significant main effect or interaction.

————INSERT TABLE 1 ABOUT HERE————

In order to understand better the distractor condition main effect, present in both target category conditions, we conducted separate analyses for the target-category distractor absent distractor conditions (A, S, and N distractor conditions) and for the target-category distractor present distractor conditions (T and T-N distractor conditions), with distractor condition and SOA as within-subjects factors. No main effects or interactions were significant when only the Target-category distractor absent conditions were considered (all *p*s > .18). However, when the Target-category distractor present conditions were analysed, the main effect of SOA was marginally significant ($F(8, 120) = 1.93$, $MSE = 229.72$, $p < .07$, $\eta_p^2 = 0.11$). Distractor condition did not have a significant main effect, neither did it interact with SOA. Those analyses suggest that the determining factor in the reduction of accuracy is the presence or absence of a target-category distractor.

To verify this claim, we averaged the accuracy data in the three target-category distractor absent conditions, in order to better estimate control performance, and we averaged the accuracy data in the two target-category distractor present conditions, in order to estimate performance in the presence of a distractor item matching the target-defining attribute, category. We then performed an ANOVA with the new distractor conditions (target-category distractor Absent, Present) and SOA as within-subjects factors (mean accuracy for each new distractor condition and SOA is plotted in Figure 2). This resulted in a significant main effect of distractor condition ($F(1, 15) = 10.72$, $MSE = 542.75$, $p < .006$, $\eta_p^2 = 0.42$), with lower accuracy in the target-category distractor Present than in the target-category distractor Absent condition (85.8% and 94.8%, respectively). The main effect of SOA was marginally significant ($F(8, 120) = 1.77$, $MSE = 80.45$, $p < .09$, $\eta_p^2 = 0.11$), as was the distractor condition X SOA interaction ($F(8, 120) = 1.76$, $MSE = 56.67$, $p < .10$, $\eta_p^2 = 0.11$). This result confirms that it is the presence or absence of a target-category distractor that determines whether attentional capture occurs, and therefore, argue in favour of the successful implementation of a top-down attentional set for a specific alphanumeric category.

————INSERT FIGURE 2 ABOUT HERE————

The present results also argue in favour of capture by the conceptual value of the target-category distractor, and not by its physical similarity with other items of the target category. If attentional capture occurred because of a general resemblance between members of a same alphanumeric category, then we might expect that a nontarget-category distractor would also capture attention, to some extent, relative to no distractor or to a symbol distractor, because digits and letters are still very similar, more so than digits or letters and symbols. However, no hint of capture by a nontarget-category distractor was present: accuracy in the N distractor condition is statistically equal to accuracy in the A and S distractor conditions (both *p*s > .14).

EXPERIMENT 2

As discussed in the introduction, several interpretations of the contingent capture effect found in Experiment 1 are plausible: the target-category distractor could draw attention to its spatial location, or could create interference with the target at higher levels of processing. In order to distinguish between spatial and non-spatial interpretations, in Experiment 2 we carried out an ERP study of the capture by alphanumeric category. We focused on the N2pc component, which we used as an index of spatially selective processing of the distractor stimuli.

METHODS

Stimuli and procedure

The stimuli and experimental design were the same as in Experiment 1, with the following exceptions. Only the distractors-target SOA that yielded a maximal capture effect in Experiment 1 was used: 233 ms, and only two distractor conditions were used: one symbol and one nontarget-category distractor (N); and one symbol and one target-category distractor (T). For the purpose of EEG recording, the character distractor (nontarget- or target-category), was presented to the left or right of the central RSVP stream on the same number of trials. Each experimental session was comprised of 30 practice trials, followed by four blocks of 160 trials, for a total of 640 experimental trials. Because we wanted participants to avoid moving their eyes during the EEG recording, they were encouraged to learn the response mapping on the numeric keypad before the experiment began, so that they would not have to look at the keyboard in order to respond. They were instructed to give accurate responses rather than fast responses and were told explicitly that speed was not important.

EEG recording and analysis

The EEG was recorded from 64 active Ag/AgCl electrodes (Biosemi Active Two system) mounted on an elastic cap following the international 10–10 standard. In addition, two electrodes recorded activity at the left and right mastoid and additional electrodes were used to monitor eye position by both the horizontal and vertical electrooculogram (HEOG and VEOG). At the time of acquisition, EEG and EOG were low-pass filtered at 67 Hz and digitized at 256 Hz; then they were referenced to the average of the left and right mastoids and high-pass filtered at 0.01 Hz (half power cut-off). Trials with blinks, eye movements, and EEG artefacts were removed prior to ERP averaging by applying automated artefact detection protocols; any participant with less than 65% of the trials remaining after this procedure was excluded from further analyses. In order to make sure that participants were fixating the central RSVP stream, the averaged HEOG signal from trials with the character distractor on the left side or on the right side were compared, in each distractor condition. Participants whose differential HEOG activity exceeded 3.2 μV (corresponding to eye movements of ~0.2°) in one or both distractor conditions in the 300 ms that followed the distractor display onset were excluded from further analyses (see Luck, 2005).

ERP averages were calculated from EEG epochs time-locked to the presentation of the distractors, with a baseline period of 200 ms pre-distractors onset. Separate ERPs were computed for each distractor condition and visual field (left or right) of the character distractor. Due to the presence of items changing every 117 ms, the ERP curves showed a steady-state like modulation that corresponded to the rate of presentation of the items in the RSVP stream (see Figure 3a and b). In order to isolate the N2pc wave from this ongoing activity, difference waves for each distractor condition were computed for the electrode pairs O1/O2, PO3/PO4, and PO7/PO8, by subtracting ERP waveforms from electrodes ipsilateral to the character distractor (nontarget- or target-category) from those from contralateral electrodes. The resulting difference waveforms were pooled across the three electrode pairs and low-pass filtered at 25 Hz. The ERP effects were quantified by measuring the mean amplitude of the pooled difference waveform for each participant and each distractor condition in two measurements windows, in which lateralized components were apparent: 135–175 ms post-distractors onset, and 200–265 ms post-distractors onset. When relevant, latency effects were evaluated using the jackknife procedure described by Ulrich and Miller (2001), with the time at which the components reached half their maximum amplitude at onset and/or offset as the latency measures (Kiesel, Miller, Jolicoeur, & Brisson, 2008).

Participants

Forty volunteer subjects (17 men, mean age = 23.0) participated in this experiment in exchange for financial compensation. All subjects reported having normal or corrected-to-normal vision. Data from one participant had to be rejected because of technical difficulties during EEG acquisition. Data from five participants were excluded from further analyses because more than 35% of the trials were rejected by the artefact rejection procedures in the EEG analyses, and one because of excessive horizontal EOG activity after artefact rejection. Hence, the data from 33 participants (14 men, mean age = 23.0) were included in the behavioural and ERP analyses[1]. For these participants, an average of 88.7% of the trials was included in the ERP analyses.

Results and Discussion

Behavioural results

Mean accuracy of target identification (shown in Table 2a) was entered into a repeated-measures ANOVA with target category (Letter, Digit) as a between-subjects factor and distractor condition (N, T) as a within-subjects factor. Results replicated the contingent capture effect observed in Experiment 1: accuracy was higher in the N than in the T distractor condition ($F(1, 31) = 18.64$, $MSE = 65.12$, *p* < .001, $\eta_p^2 = 0.38$). However, there was no main effect or interaction involving target category (both *p*s > .38).

————INSERT TABLE 2 ABOUT HERE————

Electrophysiological results

Visual inspection of the subtraction ERP curves for each distractor condition revealed two negative components contralateral to the character distractor in each distractor condition (see Figure 3c). Repeated measures ANOVAs were performed on the mean amplitude of the effects with target category condition as a between-subjects factor and distractor condition as a within-subjects factor, separately for the two time windows.

————INSERT FIGURE 3 ABOUT HERE————

No main effect or interaction emerged from analyses in the first time-window, 135–175 ms (all *p*s > .10). *T* tests against zero confirmed that both distractor conditions generated significantly greater negativities contralateral, relative to ipsilateral, to the side of presentation of the character distractor (N distractor: $t(32) = -5.01$, $p < .001$, *SEM* = 0.11; T distractor: $t(32) = -6.51$, $p < .001$, *SEM* = 0.09).

Conversely, in the 200–265 ms time window, the target category X distractor condition ANOVA yielded a main effect of distractor condition ($F(1, 31) = 10.72$, $MSE = 0.24$, $p < .004$, $\eta_p^2 = 0.26$), the T distractor eliciting a larger contralateral negativity than the N distractor, despite the fact that a significant negativity was observed in both distractor conditions (N distractor: $t(32) = -2.14$, $p < .05$, $SEM = 0.10$; T distractor: $t(32) = -5.66$, $p < .001$, $SEM = 0.11$). Neither the main effect nor the interaction involving the target category factor approached significance (both *p*s > .43).

Visual inspection of the subtraction curves suggests that the second ERP component offsets later in the T distractor condition than in the N distractor condition. Although there is a trend in that direction (offset latencies of 247.0 and 255.5 ms in the T and N distractor conditions, respectively), the difference between the two conditions (based on a jackknife analysis) did not approached statistical significance ($p > .45$).

The present electrophysiological results can be interpreted along the lines of the findings of Hopf, Boelmans, Schoenfeld, Luck, and Heinze (2004). In their study, the participants performed a visual search task in which the target was a C-shaped item with a gap to the right or to the left, defined by a specific colour (e.g., red), embedded in a search array of other C-shaped items, with gaps also to the right or to the left (relevant orientation distractors, RODs) or up or down (irrelevant orientation distractors), but never in the target colour. Note that although the distractors could match the target with regards to orientation, the only target-defining attribute was colour, that is to say, guidance by colour should be sufficient to locate the target. Nevertheless, lateralized ERP responses were observed at posterior electrode sites in response to both RODs and targets. The RODs elicited a contralateral negativity between 140 and 300 ms post-stimuli onset, with two peaks, at approximately 170 and 270 ms. This ROD-related negativity was dissociated from the N2pc to the target, which started approximately 30 ms later, at 185 ms post-stimuli onset, and overlapped with the ROD-related negativity. According to the authors, the ROD-related negativity reflects an initial stage of feature-based selection, providing a neural representation of the spatial distribution of the relevant feature values. This stage is independent of the locus of spatial attention, and is in fact followed by the focusing of attention onto the object that is most likely to be the target, reflected in the N2pc.

In the present experiment, a similar processing sequence seems to be at play. Analogous to the ROD-related negativity observed by Hopf et al. (2004), it is plausible that the contralateral negativities observed between 135 and 275 ms in the N and T distractor conditions constitute a “character-related negativity,” and that the difference of amplitude between the N and T distractor conditions in the 200–265 ms time-window is the N2pc effect. Indeed, while the target-defining attribute was alphanumeric category, items of the nontarget-category still shared a general featural configuration with the set of potential targets. Hence, it is possible that members of both digit and target categories, whatever the target category was, were processed differentially relative to the symbol distractor because their features were more similar to the searched-for features. However, the N2pc was generated only by distractors of the target-category, because they matched the target with regards to the target-defining attribute, which caused visuospatial attention to be deployed to their location. The difference between the ERP subtraction curves for the T and N distractor conditions is plotted in Figure 3d, and will be discussed further in Experiment 3.

EXPERIMENT 3

Experiment 3 was designed to test the hypothesis that the initial contralateral negativity observed both for target-category and non-target-category distractors found in Experiment 2 reflects an early, possibly feature-based character-related negativity. A third distractor condition was added, in which the distractor display was comprised of one target-category distractor, and one nontarget-category distractor. The ERPs in this condition were defined relative to the side of presentation of the target-category distractor. If it is true that both digit and letter distractors receive feature-based selective processing reflected in a character-related negativity, but that only target-category distractors receive spatial attentional processing reflected in the N2pc, then in this new condition, the character-related negativity should be cancelled out, because it would be present in both hemispheres, and only the N2pc should be present, reflecting the differential attentional processing of the target-category distractor over the nontarget-category distractor.

METHODS

Stimuli, Procedure, and EEG recording and analyses

The stimuli, experimental design, and EEG recording and analyses were the same as in Experiment 2, with the following exceptions. Three distractor conditions were used: one symbol and one nontarget-category distractor (N); one symbol and one target-category distractor (T); and one target-category and one nontarget-category distractor (T-N). In the T-N distractor condition, the ERPs were computed contralateral and ipsilateral relative to the side of presentation of the target-category distractor. Each experimental session was comprised of 30 practice trials, followed by five blocks of 144 trials, for a total of 720 experimental trials.

Participants

Thirty-seven volunteer subjects (14 men, mean age = 21.7) participated in this experiment in exchanged for financial compensation. All subjects reported having normal or corrected-to-normal vision. Data from four participants were excluded from the analyses because of excessive horizontal EOG activity after artefact rejection. The remaining 33 participants (14 men) had a mean age of 21.8 years. For these participants, an average of 89.5% of the trials was included in the ERP analyses.

Results and Discussion

Behavioural results

Table 2b shows mean accuracy of target identification for each target category (Letter, Digit) and distractor condition (N, T, T-N). These data were subjected to a repeated-measures ANOVA with target category as a between-subjects factor and distractor condition as a within-subjects factor, which revealed, as expected, a main effect of distractor condition ($F(2, 62) = 35.02$, $MSE = 10.89$, $p < .001$, $\eta_p^2 = 0.53$). This effect was driven by the fact that accuracy was lower when the distractor display contained one target-category distractor than when it did not (T vs. N distractor conditions: $t(32) = 6.73$, $p < .001$, $SEM = 0.88$; T-N vs. N distractor conditions: $t(32) = 7.26$, $p < .001$, $SEM = 0.84$). The T and T-N distractor conditions yielded statistically identical accuracy ($p > .82$). There was no main effect or interaction involving target category (both *p*s > .64).

Electrophysiological results

As can be seen in Figure 4a, the subtraction ERP curves for the Target-category and Nontarget-category distractor conditions replicate the results from Experiment 2, with two negative components contralateral to the character distractor present in each distractor condition, roughly in the same time intervals as in Experiment 2. However, the subtraction curve for the Target- and nontarget-category distractors condition (T-N) displays a different pattern. Repeated measures ANOVAs were performed on the mean amplitude of the subtraction curves with target category condition as a between-subjects factor and distractor condition as a within-subjects factor, separately for the two time windows.

————INSERT FIGURE 4 ABOUT HERE————

In the 135–175 ms time interval, only the main effect of distractor condition was significant ($F(2, 62) = 3.34$, $MSE = 0.23$, $p < .05$, $\eta_p^2 = 0.10$). Contralateral negativities significantly greater than zero were observed only in the N ($t(32) = -3.58$, $p < .001$, $SEM = 0.08$) and T ($t(32) = -4.39$, $p < .001$, $SEM = 0.09$) distractor conditions, but not in the T-N distractor condition ($t(32) = -1.19$, $p > .24$, *SEM* = 0.08). No main effect or interaction involving target category was observed (both *p*s > .46).

In the 200–265 ms time window, the main effect of distractor condition was also significant ($F(2, 62) = 3.97$, *MSE* = 0.24, $p < .03$, $\eta_p^2 = 0.11$). Although all three distractor conditions generated significant lateralized effects (N distractor: $t(32) = -2.35$, $p < .03$, *SEM* = 0.10; T distractor: $t(32) = -6.41$, $p < .001$, *SEM* = 0.09; T-N distractor: $t(32) = -4.52$, $p < .001$, *SEM* = 0.09), the T distractor-generated negativity was significantly larger than the N distractor-generated negativity ($t(32) = 4.50$, $p < .001$, *SEM* = 0.08). The negativity in response to the T-N distractor condition did not differ significantly from either the N or T distractor condition (T-N vs. N distractor conditions: $t(32) = 1.12$, $p > .27$, *SEM* = 0.14; T-N vs. T distractor conditions: $t(32) = -1.51$, $p > .14$, *SEM* = 0.13).Neither the main effect nor the interaction involving the target category factor approached significance (both *p*s > .69).

As was the case in Experiment 2, there was a trend for longer latencies of the offset of the N2pc in the T and T-N distractor conditions (261.3 and 270.1 ms, respectively) relative to the N condition (251.9 ms) that was visible in the subtraction curves. However, the effect of distractor condition on N2pc offset latency was not significant ($F(2, 64) = 0.993$, *MSE* = 0.24, $p > .37$); neither were the differences between any pair of conditions (all *p*s > .15).

The present results support the interpretation that characters of both categories elicit a character-related negativity, because of their physical resemblance with the potential targets with regards to their general featural configuration, while only target-category distractors generate a shift of visuospatial attention to their location, indicated by the presence of an N2pc. The T and N distractor conditions replicate the results of Experiment 2: a similar ERP effect in the 135–175 ms post-distractors onset time-window, with the contralateral negativity growing larger in the T distractor condition relative to the N distractor condition as the N2pc to the target-category distractor develops. Hence, activity in both time windows in the N distractor condition appears to be due to a character-related negativity, whereas activity in the T distractor condition is the sum of the character-related negativity and of the N2pc to the target-category distractor. The results of the third distractor condition, T-N, supports this interpretation: no contralateral activity is observed in the 135–175 ms time window. This was predicted, because both hemifields contained a character distractor, which means that a character-related negativity was to be expected at both ipsilateral and contralateral posterior electrode scalps relative to the side of presentation of the target-category distractor. Hence, these character-related negativities would have been cancelled out in the subtraction of ipsilateral form contralateral curves relative to the side of presentation of the target-category distractor. However, the N2pc is clearly present in this condition, in the 200–265 ms time window. This supports the view that even though both peripheral distractors were characters, and in that way, they were not easily differentiated at the feature level, a character that matched the target category received spatially specific attentional processing, indicative of a shift of visuospatial attention to its location. Moreover, we note that the N2pc in the T-N distractor condition onsets at approximately the same point in time at which the N and T distractor conditions ERPs begin to diverge. To verify this claim, we computed the difference between the subtraction waveforms in the N and T distractor conditions, (T minus N), thus eliminating the shared activity between the two conditions. This new subtraction waveform is plotted along the subtraction waveform for the T-N distractor condition in Figure 4b. We can clearly see that the two effects are extremely similar, both in latency and in morphology. Therefore, we argue that the N2pc is represented in the difference between the ERPs to the T and N distractors, and that no N2pc was observed in the N distractor condition, both in the present Experiment and in Experiment 2 (see Figure 3d). This reinforces the interpretation that the current findings are the result of overlapping activity due to 1) a feature-specific processing of the character distractors because of their common featural configuration with the set of potential targets, and 2) a spatially specific attentional processing of the target-category character, on which visuospatial attention is focused.

EXPERIMENT 4

Even though we argued that only target-category distractors generated an N2pc in Experiments 2 and 3, it could be argued that this effect was driven not by the conceptual value on the distractors category, but by physical features that cause a digit to look more like other digits than like letters, and vice-versa. The fact that no behavioural capture effect whatsoever was observed in the nontarget-category distractor condition, even when compared to a distractor-absent condition in Experiment 1, strongly argues against this alternative interpretation. However, given the mixed findings regarding the importance of featural differences between letters and digits in the category effect, Experiment 4 was designed to study the behavioural and electrophysiological effects of irrelevant distractors that matched or did not match the target category, with a stimulus set in which we eliminated differences in low level features between letters and digits.

METHODS

Stimuli, Procedure, and EEG recording and analyses

The stimuli, experimental design, and EEG recording and analyses were the same as in Experiment 3, with the following exceptions. Seven-segment box characters, similar to those seen on digital clocks and other electronic devices, were used (see Figure 5). The digit set was comprised of the digits 2, 3, 4, 7, and 9, and the letter set, of the letters A, F, H, L, and P. These particular digits and letters were chosen because 1) no two characters were identical in their box form, to avoid confusion, and 2) each digit was paired with one letter with regards to the number of line segments in its box form, so that the average luminance and the intra- and inter-category similarities were the comparable for both sets. Each character and the # symbol occupied 0.65° in width and 1.3° in height. The task was to report the identity of the target character using the “N”, “U”, “I”, “O”, and “P” keys on the keyboard. These keys were chosen so that the participants’ right hand could rest naturally on the keyboard, with each finger resting on one of the response keys. Hence, the participants were instructed to keep their hand in place on the keyboard, and to answer “2” (or “A”) with their thumb (which sat on the “N” key), “3” (or “F”) with their index finger (on the “U” key), and so on. In order to help participants remember the response mapping, the entire set of possible targets was presented as the response prompt, in the same order as in the mapping (e.g., “AFHLP?”). The participants were encouraged to take their time to respond accurately and without moving their eyes, as speed was not important.

——————INSERT FIGURE 5 ABOUT HERE——————

Participants

Twenty-three volunteer subjects (5 men, mean age = 23.1) participated in this experiment in exchange for financial compensation. All subjects reported having normal or corrected-to-normal vision. The data from two participants were excluded from the analyses because an excessive number of the trials were rejected by the artefact rejection procedures in the EEG analyses. Data for three more participants were excluded because of excessive horizontal EOG activity after artefact rejection. The remaining 18 participants (2 men) had a mean age of 22.1 years. For these participants, an average of 84.5% of the trials was included in the ERP analyses.

Results and Discussion

Behavioural results

Table 2c shows mean accuracy of target identification for each target category (Letter, Digit) and distractor condition (N, T, T-N). The results replicated those of Experiment 3. A repeated-measures ANOVA with target category as a between-subjects factor and distractor condition as a within-subjects factor, revealed a main effect of distractor condition ($F(2, 32) = 8.58$, $MSE = 8.15$, $p < .002$, $\eta_p^2 = 0.35$). As in Experiment 3, accuracy was lower when the distractor display contained one target-category distractor than when it did not (T vs. N distractor conditions: $F(1, 17) = 29.61$, $MSE = 4.43$, $p < .001$, $\eta_p^2 = 0.64$; T-N vs. N distractor conditions: $F(1, 17) = 5.79$, $MSE = 11.80$, $p < .03$, $\eta_p^2 = 0.25$). The T and T-N distractor conditions yielded statistically identical accuracy ($p > .28$). There was no main effect or interaction involving target category (both *p*s > .32).

Electrophysiological results

Figure 6a shows the subtraction ERP curves for each distractor condition. The pattern of results replicate what was observed in Experiment 3. Repeated measures ANOVAs were performed on the mean amplitude of the subtraction curves with target category condition as a between-subjects factor and distractor condition as a within-subjects factor, separately for the two time windows.

————INSERT FIGURE 6 ABOUT HERE————

In the 135–175 ms time interval, the main effect of distractor condition was significant ($F(2, 32) = 22.35$, $MSE = 0.39$, $p < .001$, $\eta_p^2 = 0.58$), and was driven by the fact that only the N and T distractor conditions generated significant lateralized negativities (N distractor: $t(17) = -5.30$, $p < .001$, $SEM = 0.23$; T distractor: $t(17) = -6.13$, $p < .001$, $SEM = 0.20$), whereas the amplitude of the ERP subtraction curve in the T-N distractor condition was not significantly different from zero in this time-window ($t(17) = -0.19$, $p > .85$, $SEM = 0.13$). The target category X distractor condition interaction was also significant ($F(2, 32) = 6.66$, $MSE = 0.39$, $p < .005$, $\eta_p^2 = 0.29$), reflecting the slightly larger amplitude of the lateralized negativity elicited in the N and T distractor conditions for participants searching for a letter (-1.67 and -1.62 µV, respectively) than for participants searching for a digit (-0.79 and -0.85 µV, respectively), while a reversed effect was observed in the T-N distractor condition (0.22 and -0.27 µV in the Letter and Digit target category conditions, respectively). Separate *t* tests conducted for each distractor condition with target category as the grouping factor confirmed this observation, with marginally significant main effects of target category for the three distractor conditions (N distractor: $t(16) = -2.09$, $p < .06$; T distractor: $t(16) = -2.09$, $p < .06$; T-N distractors: $t(16) = 1.99$, $p < .07$). However, the N and T distractor conditions elicited contralateral negativities larger than zero in both target category conditions (N distractor, Letter target category: $t(8) = -4.58$, $p < .003$, $SEM = 0.37$, Digit target category: $t(8) = -3.64$, $p < .008$, $SEM = 0.22$; T distractor, Letter target category: $t(8) = -6.27$, $p < .001$, $SEM = 0.25$, Digit target category: $t(8) = -3.24$, $p < .02$, $SEM = 0.26$), contrary to the T-N distractor condition, which yielded null effects in both target category conditions (both *p*s > .19).

In the 200–265 ms time window, there was no main effect or interaction involving target category or distractor condition (all *p*s > .11). However, the T distractor condition did generate a larger N2pc than the N distractor condition ($t(17) = 2.48$, $p < .03$, $SEM = 0.14$), consistent with the results from the previous experiments. Moreover, when analysed separately in *t* tests against zero, only the T and T-N distractor conditions yielded significant effects (T distractor: $t(17) = -3.41$, $p < .004$, $SEM = 0.15$; T-N distractors: $t(17) = -3.37$, $p < .005$, $SEM = 0.13$), whereas the Nontarget-category distractor condition did not ($p > .33$).

The effect of distractor condition on the N2pc offset latency visible in the subtraction curves was significant ($F(2, 34) = 22.49$, $p < .001$): the T-N distractor condition generated a longer-lasting N2pc (offset latency: 276.7 ms) than both the N ($F(1, 17) = 23.14$, $p < .001$) and the T ($F(1, 17) = 24.94$, $p < .001$) distractor conditions (offset latencies: 225.0 and 248.2 ms, respectively). The difference between the latter two conditions was not significant (p > .84).

The electrophysiological effects observed in Experiment 3 were replicated in the present experiment. Once again, we observed a character-related negativity in the N and T distractor conditions that was significant in the 135–175 ms time window, and the ERPs generated by those two conditions started to diverge when the N2pc to the target-category distractor began to develop, at the same time as the N2pc to the target-category distractor observed in the T-N distractor condition. The T minus N subtraction performed for Experiments 2 and 3 is replicated with the data from Experiment 4 in Figure 6b, plotted with the subtraction waveform for the T-N distractor condition, and we can see once again that the N2pc elicited in the T and T-N distractor conditions are similar (the latency differences at onset and offset are not significant, both *p*s > .52). In the T-N distractor condition, no character-related negativity was observed, presumably because it was present in both hemispheres and, as such, cancelled out in the comparison between ipsilateral and contralateral ERP responses relative to the side of presentation of the target-category distractor.

One difference between the previous experiments and Experiment 4 however, is that the character-related negativity was much larger in Experiment 4 than in Experiments 2 and 3 in the 135–175 ms measurement window (mean amplitudes of -0.58, -0.36, and -1.23 µV in Experiments 2, 3, and 4, respectively, collapsed across the N and T distractor conditions). In Experiments 2 and 3, a roman font was used, and the character sets, both digits and letters, were quite heterogeneous with regards to physical features and configuration, whereas in Experiment 4, the box characters made the character set rather homogeneous. Indeed, the latter characters displayed a great amount of overlap in their traits, and their general configuration was very similar. Therefore, because each character in Experiment 4 shared a greater featural resemblance with each potential target, it is not surprising that the character-related negativity, elicited by a match in low-level features between the items in the display and the target template, was larger in this experiment. Alternatively, the difference across experiments could be due to the relative low-level differences between the character sets and the symbol (#) distractor in the three experiments. Although the symbol distractor was very similar across experiments, it was not the case for characters, as was just mentioned. In Experiment 4, none of the box characters overlapped with the symbol distractor, which also differed with the character set in its configuration: two line endings were present on each side, and no full line or corner was present on either side (see Figure 5). Therefore, it is possible that the symbol distractor shared even fewer features with the target template in Experiment 4, where the characters were more similar to each other and more distinct from the symbol distractor, than in Experiments 2 and 3, where the symbol distractor probably had more traits in common with the character set, itself being comprised of less similar items. Therefore, it is possible that the symbol distractor received some feature-specific processing in Experiments 2 and 3, but not (or less) in Experiment 4. Hence, because the character-related negativity is postulated to reflect feature-specific processing, the subtraction of contralateral minus ipsilateral waveforms would yield a larger effect in Experiment 4 than in Experiments 2 and 3.

However, note that this amplitude effect on the character-related negativity was not observed in the 200–265 ms time-window, where it was rather small in all three experiments (mean amplitude in the N distractor condition: -0.21, -0.23, and -0.17 µV in Experiments 2, 3, and 4, respectively). This suggests that different processes underlie the two portions of the character-related negativity. Likewise, the amplitude of the N2pc was similar across experiments (mean amplitude in the T distractor condition, where the N2pc overlaps with the second portion of the character-related negativity: -0.60, -0.59, and -0.51 μV in Experiments 2, 3, and 4, respectively; mean amplitude in the T-N distractor condition: -0.39 and -0.42 μV, in Experiments 3 and 4, respectively). It thus seems as though when the target is defined by a conceptual attribute, the amplitude of the N2pc is not influenced by the degree to which the physical features of the capturing distractor match the target template, with the degree of capture governed more by category membership than by low-level similarity (at least, under conditions in which the two conceptual categories are composed of highly similar exemplars, as are letters and digits).

The results from Experiment 4 replicate those of the previous experiments, under conditions in which the differential effects of the target-category distractor and nontarget-category distractor on behavioural and electrophysiological results cannot be explained by featural differences between members of both categories. According to Cardosi (1986), with the typeface used in the present experiment, it is possible to compute a similarity index for each character in the stimulus set, in order to verify if items in one category are more similar to each other (within-category, or WC, similarity) than to members of the opposite category (between-category, or BC, similarity). To do that, we must calculate the total number of line segments in common between each item and, on the one hand, other items belonging to the same category (WC), and, on the other hand, items of the opposite category (BC). The difference between those two sums (WC - BC) is referred to as the within-category similarity index; if the index is positive, it means that the character resembles other characters in its category more than characters of the opposite category (and even more so as the index increases). On the contrary, a negative index indicates that the character has more features in common with member of the opposite category than of its own category.

In our study, unlike Cardosi's (1986), the target and distractor items were drawn from the same pool of items, meaning that when computing the WC and BC similarity for a letter, we would be comparing this letter with five digits, but with only four letters. Hence, we modified the computation method of the similarity index to better suit our stimulus set. The first modification we applied was to compute the mean, instead of total, number of line segments in common, in order to accommodate the fact that the number of items taken into account was not the same in each category. Second, instead of comparing WC and BC similarity, we compared similarity with items of the letter stimulus set (Letters), and with items of the digit stimulus set (Digits), and we subtracted the mean Digits similarity from the mean Letters similarity. The mean Letters - Digits similarity index was positive if the character resembled items in the letter stimulus set more than items in the digit stimulus set, and vice-versa. Table 3 shows the Letters and Digits mean as well as the difference between the two for each character in the stimulus set, and the average similarity index for each category. The average similarity index was positive for letters (0.54) and negative for digits (-0.44), indicating that each character tended to resemble more, on average, members from its own category than from the opposite category. Although average similarity indexes for both categories of characters were small (suggesting that each item resembles more items from its own category by approximately half a line segment, when items are composed, on average, of 4.6 line segments), the difference between the two was reliable ($t(8) = 3.07$, $p < .02$, $SEM = 0.32$). Therefore, there remains the slight possibility that the observed effects of target-category distractors were due, in part, to featural differences between the target and nontarget categories.

However, several aspects of the results allow us to argue against this interpretation. First, the character-related negativity, that arises in response to the presence of target-relevant features, does not reflect the fact that items of the same category could share a greater physical resemblance than items of different categories. If there was such an imbalance, and that this difference in physical features between categories could be detected and processed by the visual system, we would expect to observe a greater character-related negativity in response to target-category distractors than in response to nontarget-category distractors. That would lead to a greater character-related negativity in the T distractor condition than in the N distractor condition, and to a small character-related negativity in the T-N distractor condition, resulting from the subtraction of the character-related negativity generated by the nontarget-category distractor from the greater character-related negativity generated by the target-category distractor. However, there is no trace of such patterns of results in the present data. Second, if similarity in physical features between items of the stimulus set was critical of the capture of visuospatial attention, we would expect attention to be captured, to a certain extent, by distractors of the nontarget category, which are relatively similar to items of the target category, or at least, more so than symbol distractors. If that was the case, we would observe an increased behavioural interference in the T-N distractor condition relative to the T distractor condition, in addition to an N2pc in response to nontarget-category distractors, although perhaps smaller than the N2pc generated by target-category distractors. This N2pc would be visible in the N distractor condition, but also as a diminution in the amplitude of the N2pc observed in the T-N distractor condition, relative to the N2pc observed in the T distractor condition (visible in the T minus N subtraction curve plotted in Figure 6b). However, once again, there is no hint of an effect of nontarget-category distractors either in the behavioural or electrophysiological results. Therefore, we argue that it is the conceptual value of alphanumeric category, and not the physical attributes associated with alphanumeric category, that caused the pattern of contingent attentional capture observed in the present experiment.

————INSERT TABLE 3 ABOUT HERE————

GENERAL DISCUSSION

The first goal of the present study was to establish if it is possible to implement a top-down attentional set in favour of a conceptual attribute, namely, alphanumeric category, such that attention is captured by irrelevant items sharing this categorial membership. Using a paradigm modified from Leblanc and Jolicoeur (2005), in which the target was defined as the only letter in an RSVP stream of digits, or vice-versa, Experiment 1 demonstrated an attentional capture effect that was indeed contingent on category membership. When distractors were presented outside the focus of attention shortly before the target, accuracy in the report of the target identity dropped if one of those distractors belonged to the target category, whether it was presented along with a symbol or a nontarget-category distractor. In contrast, a nontarget-category distractor did not affect target report — participants maintained the same level of performance as when two symbol distractors or no distractors at all were presented.

Having found that a contingent capture effect was obtained in response to alphanumeric category, our second goal was to study the locus of this effect. It had been shown that contingent capture by simple features such as colour resulted from a shift of visuospatial attention to the location of the capturing distractor, that is to say, the item that matched the top-down attentional set in favour of the target-defining attribute elicited an N2pc (Brisson et al., 2009; Eimer & Kiss, 2008; Kiss, Jolicoeur, et al., 2008; Leblanc et al., 2008; Lien et al., 2008). Because the N2pc indexes the locus of visuospatial attention, the presence of the N2pc corroborated the visuospatial locus of the contingent capture effect. In Experiments 2, 3, and 4, in addition to replicating the behavioural contingent capture effect described in Experiment 1, we found that target-category distractors generating these capture effects also generated an N2pc. This indicates that even if capture is contingent on a conceptual attribute, it results from interference, at least in part, at the visuospatial level. However, we note that alphanumeric category is a particularly overlearned conceptual classification, and that this result may not generalize to other conceptual categories.

In the past, alphanumeric category effects, observed mainly in the context of visual search, have been questioned because of the possibility that they might have been due to featural differences rather than to abstract category membership, *per se*. In other words, it is possible that on average, each digit resembles more other digits than letters, and vice-versa, and that participants use these physical differences between categories to guide their attention to members of the target category faster in the context of between-category search, whereas this kind of cue would not be available in within-category search. Attempts to balance within- and between-category similarity have yielded mixed results, some authors coming to the conclusion that category effects were in fact due to differences in low-level features (Cardosi, 1986; Duncan, 1983; Krueger, 1984), and others maintaining the interpretation of the category effect as a conceptual effect (Dixon & Shedden, 1987, Experiment 2; Dux & Coltheart, 2005; Gleitman & Jonides, 1976, Experiment 1; Ingling, 1972; Jonides & Gleitman, 1972).

In the present study, the fact that nontarget-category distractors did not affect target report relative to conditions in which no distractors, or only symbol distractors are present, despite the fact that they were more similar to the target set than symbol distractors (or, of course, than an absent distractor), argues against an interpretation of the contingent capture effect based on physical similarity between the target set and the target-category distractors. Nevertheless, Experiment 4 was designed to rule out this possibility. A seven-segment box character set was used, which abolished the featural differences between letters and digits. In fact, a similarity analysis suggested that with this procedure, between-category similarity was greater than within-category similarity. Even under these conditions, the behavioural and electrophysiological effects of attentional capture contingent on alphanumeric category were observed, that is to say, a drop in target report and an N2pc effect when a peripheral target-category distractor was presented shortly before the target.

In addition to the N2pc, another lateralized component was observed in Experiments 2, 3, and 4. This component, that we termed the character-related negativity, following the work of Hopf et al. (2004) on the ROD-related negativity, consisted in a greater negativity at posterior electrode sites contralateral, relative to ipsilateral, to character distractors when the other hemifield contained a symbol distractor. Consistent with the interpretation of Hopf and colleagues (2004), it appears that this effect is due to a match between the target features and the distractors features. This analysis of the visual display would enable the detection and localization of task-relevant features (in this case, presence of a character), before the deployment of visuospatial attention to the location of the object that is most likely to be the target (the target-category character), indexed by the N2pc effect. It is interesting to note that while this process was observed in the presence of both target- and non-target category characters, only target-category characters generated an N2pc and a behavioural capture effect. Hence, it looks as though this initial feature-selective processing of items of the visual display does not require attentional engagement.

Moreover, in the context of the present study, the finding of two distinct components allows a tentative dissociation between a processing stage in which featural similarity is critical, indexed by the character-related negativity, and another in which only conceptual attributes are important, indexed by the N2pc, in a context where the conceptual attributes are critical to distinguish the target from other items, or, in other words, where the features alone do not allow a clear distinction between the relevant and irrelevant categories. In that way, this finding reinforces the view that contingent capture by alphanumeric category is the result of 1) the establishment of an attentional set in favour of the conceptual digit or letter category, rather than in favour of a set of physical properties specific to digits or letters, and 2) of a shift of visuospatial attention to the location of items matching this target category.

Finally, the present results bring further support to the contingent capture hypothesis, and prove problematic for an interpretation of capture claiming that attention is captured by the bottom-up salience of stimuli (Theeuwes et al., 2000). In the present study, we used sets of stimuli that were perfectly equated in terms of bottom-up salience and physical features, ensuring that the contribution of low-level characteristics was abolished, especially when a target-category distractor and a nontarget-category distractor were presented within the same display. Under these conditions, the observation of capture effects, both in the behavioural and in the electrophysiological domains, can be explained only by top-down factors, namely, by the correspondence between the attentional set and the stimulus attributes. This is not to say that attention can never be captured by singletons, by virtue of their bottom-up salience. Rather, we demonstrate, once again, that bottom-up salience is not a necessary condition for attentional capture to occur.

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AUTHOR NOTE

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FOOT NOTE

[1]After testing half of the participants, we discovered that our distractor display was not perfectly balanced on the physical level: the symbol (#) distractor was slightly more luminous (18.3 cd/m^2) than the average of the stimuli in the letter (14.7 cd/m^2) and digit sets (14.2 cd/m^2), which could have affected early lateralized ERP responses — but this difference could not explain a difference across the letter vs. digit category manipulation. First, the amplitude of the N2pc is not affected by the strength of the bottom-up signal (Brisson, Robitaille, & Jolicoeur, 2007). Second, even if it was the case that the symbol distractor, because of its greater salience (either sensory or perceptual), generated larger ERP responses than the less salient characters, this effect would be in the opposite direction relative to our observations (i.e., larger ERPs contralateral to the symbol distractor, and not contralateral to the target-category character distractor). Nevertheless, the symbol distractor was adjusted to correct this imbalance by making its lines thinner. Of the final 32 participants considered in the analyses, 17 were tested with the first version, and 16 with the second version of the experiment. All statistical analyses were first performed with Version as a between-subjects factor, but neither the main effect nor any interaction with other factors reached significance, neither in the behavioural nor in the ERP analysis. Therefore, both versions of the experiment were treated as one and this factor is not considered further.

TABLE 1

Mean percent correct target identifications for each target category, distractor and distractors-target SOA condition.

	Mean Accuracy (%)									
Target Category	Letter					Digit				
Distractor	A	S	N	T	T-N	A	S	N	T	T-N
SOA (ms)										
0	92.2	89.1	93.8	79.7	79.7	96.9	96.8	93.0	92.7	91.4
117	92.2	92.2	95.3	75.0	73.4	90.0	97.0	95.5	92.7	92.5
233	95.3	96.9	89.1	76.6	71.9	98.4	98.6	98.4	91.4	84.7
350	95.3	92.2	87.5	73.4	68.8	98.6	94.6	91.1	92.0	90.8
467	95.3	93.8	93.8	79.7	70.3	93.7	95.7	93.9	90.8	94.0
583	98.4	93.8	89.1	84.4	85.9	96.9	95.7	98.4	89.0	92.8
700	91.7	95.7	95.3	81.3	83.7	98.6	98.6	98.2	92.0	92.5
817	96.9	93.8	93.8	87.5	81.3	98.2	96.1	95.1	92.7	96.9
933	90.6	90.6	95.3	89.1	90.6	98.4	97.5	95.5	92.5	95.1

TABLE 2

Mean percent correct target identifications for each target category and distractor condition, for Experiments 2, 3, and 4.

	Mean Accuracy (%)					
Target Category	Letter			Digit		
Distractor	N	T	T-N	N	T	T-N
A) Experiment 2	90.9	82.3	–	94.1	85.6	–
B) Experiment 3	91.3	85.9	85.6	90.5	84.2	84.2
C) Experiment 4	90.3	86.1	86.2	86.7	83.2	85.4

TABLE 3

Differences between the total number of line segments common to each character and other characters of the same (WC) or of the opposite (BC) categories in Experiment 4.

	Mean number of line segments in common			
Character	Letters	Digits	Letters - digits	Mean
Letters				
A	4.00	4.00	0.00	
F	3.25	2.20	1.05	
H	3.50	3.20	0.30	0.54
L	2.00	1.20	0.80	
P	3.75	3.20	0.55	
Digits				
2	3.20	3.00	0.20	
3	2.60	3.75	-1.15	
4	2.80	2.75	0.05	-0.44
7	1.60	2.50	-0.90	
9	3.60	4.00	-0.40	

FIGURE CAPTIONS

Figure 1. Illustration of the sequence of events in each trial and of distractor conditions in Experiment 1.

Figure 2. Percent correct target identifications in the target-category distractor Present (T and T-N distractor conditions collapsed) and target-category distractor Absent (A, S, and N distractor conditions collapsed) conditions, for each distractors-target SOA, with 95% confidence intervals calculated as suggested by Loftus and Masson (1994) for within-subjects designs.

Figure 3. Panels A and B: pre-subtraction ERP waveforms ipsilateral and contralateral to the character distractor in the N (A) and T (B) distractor conditions in Experiment 2. Panel C: ERP subtraction waveforms for each distractor condition in Experiment 2. Panel D: Subtraction of the T distractor condition subtraction waveform minus the N distractor condition subtraction waveform in Experiment 2.

Figure 4. Panel A: ERP subtraction waveforms for each distractor condition in Experiment 3. Panel B: Subtraction of the T distractor condition ERP subtraction waveform minus the N distractor condition ERP subtraction waveform, plotted with the ERP subtraction waveform for the T-N distractor condition in Experiment 3.

Figure 5. The stimulus set used in Experiment 4.

Figure 6. Panel A: ERP subtraction waveforms for each distractor condition in Experiment 4. Panel B: Subtraction of the T distractor condition ERP subtraction waveform minus the N distractor condition ERP subtraction waveform, plotted with the ERP subtraction waveform for the T-N distractor condition in Experiment 4.

FIGURE 1

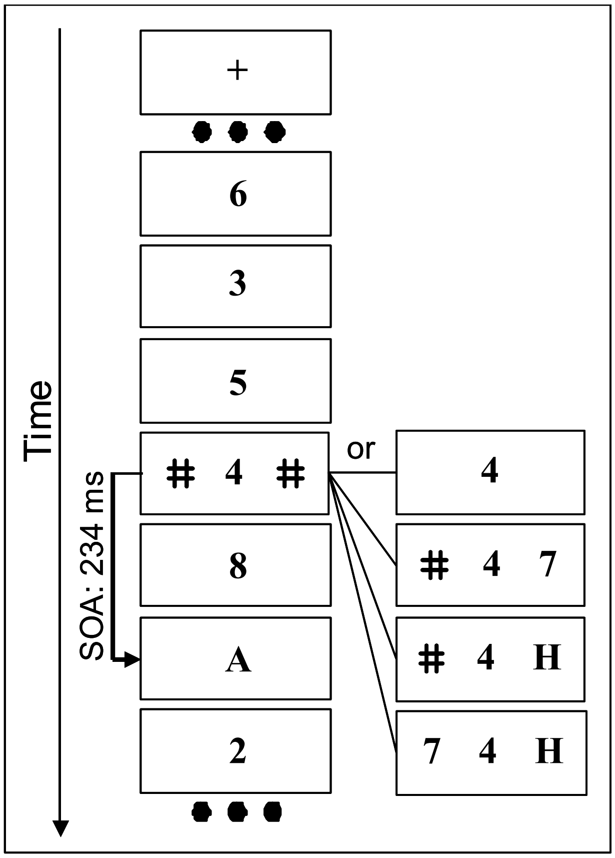
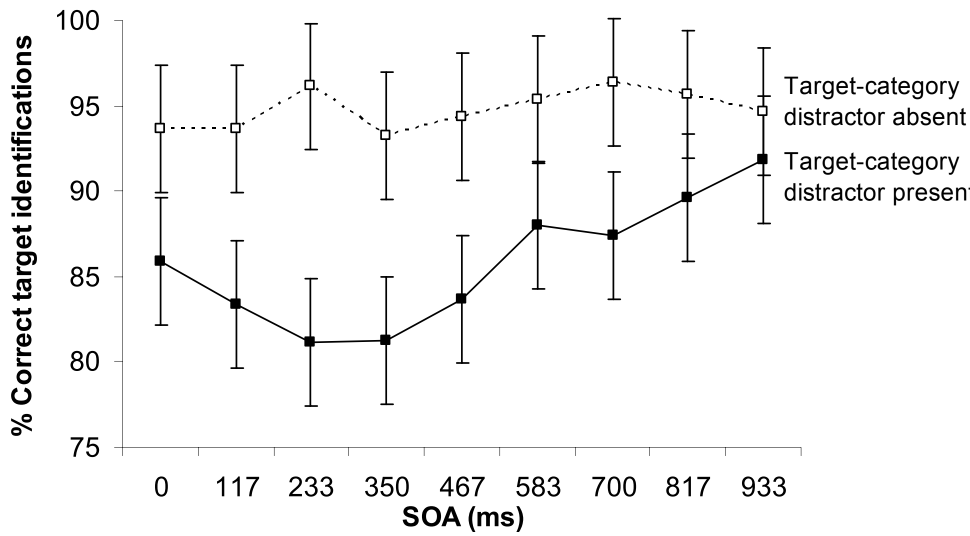


FIGURE 2



100
95
90
85
80
75
% Correct target identifications
0
117
233
350
467
583
700
817
933
SOA (ms)
Target-category distractor absent
Target-category distractor present

FIGURE 3

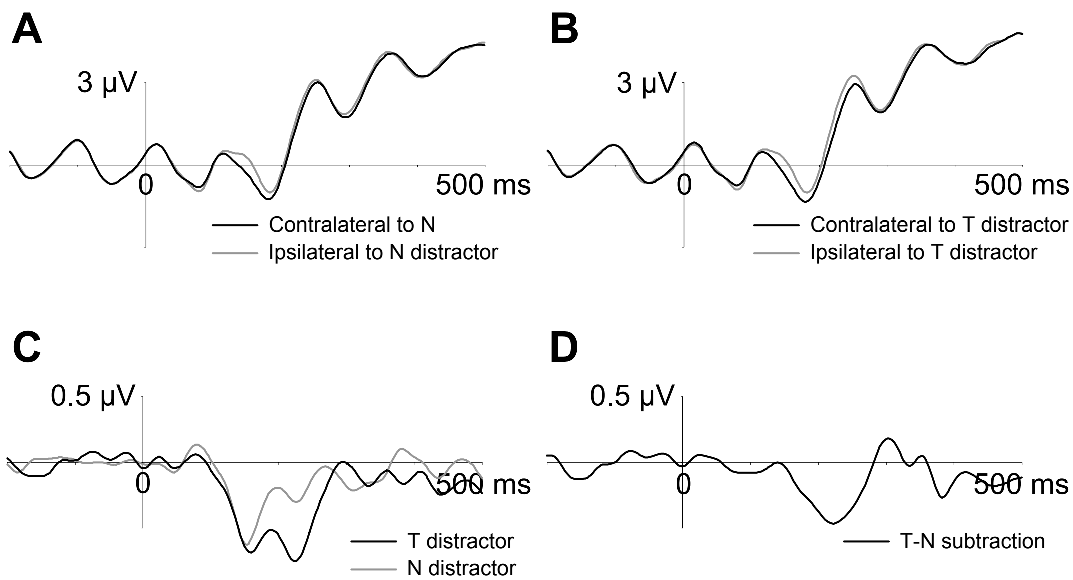

A
3 µV
0
500 ms
Contralateral to N
Ipsilateral to N distractor
B
3 µV
0
500 ms
Contralateral to T distractor
Ipsilateral to T distractor
C
0.5 µV
0
500 ms
T distractor
N distractor
D
0.5 µV
0
500 ms
T-N subtraction

FIGURE 4

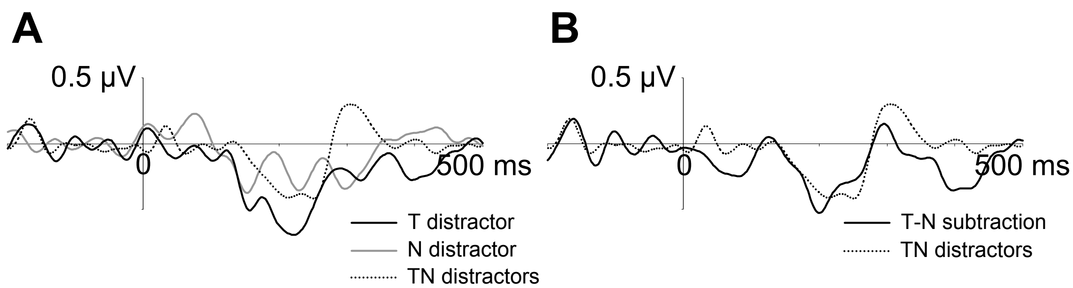

A
0.5 µV
0
500 ms
T distractor
N distractor
TN distractors
B
0.5 µV
0
500 ms
T-N subtraction
TN distractors

FIGURE 5

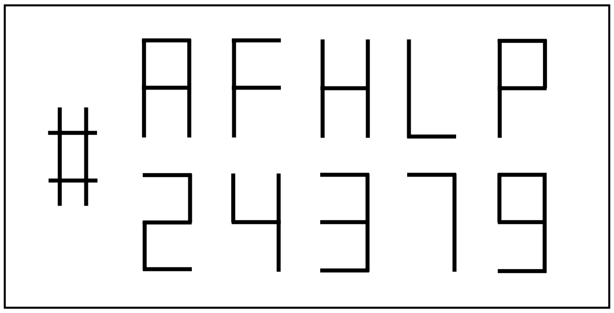
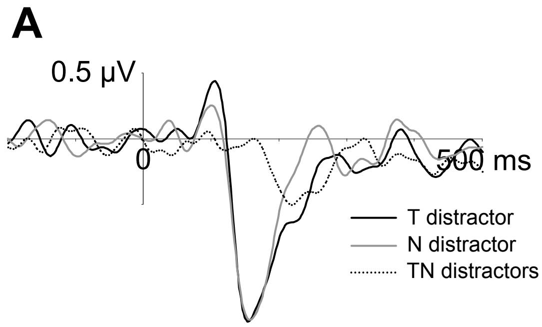


FIGURE 6


A
0.5 µV
0
500 ms
T distractor
N distractor
TN distractors
B
0.5 µV
0
500 ms
T-N subtraction
TN distractors

DISCUSSION GÉNÉRALE

CONCLUSIONS

La présente thèse a permis d'approfondir notre compréhension du phénomène de capture contingente de l'attention en en explorant trois principaux aspects. Premièrement, la nature de l'interférence : dans quelle mesure le déficit de performance symptomatique de la capture contingente de l'attention peut-il être expliqué par un déplacement de l'attention visuospatiale, par rapport à de l'interférence à d'autres niveaux de traitement? Deuxièmement, la cause de l'interférence : la capture attentionnelle peut-elle être due seulement à une correspondance entre les contrôles attentionnels descendants et les propriétés des stimuli, ou encore la saillance ascendante des stimuli joue-t-elle un rôle essentiel dans le déclenchement de la capture, qui pourrait toutefois être modulée à des stades de traitement ultérieurs par les contrôles attentionnels? Troisièmement, la complexité des contrôles attentionnels descendants : est-il possible d'établir des contrôles attentionnels en faveur d'une propriété conceptuelle, plutôt que physique, ce qui se traduirait par une capture attentionnelle contingente à cette propriété de haut niveau?

LA NATURE DE LA CAPTURE CONTINGENTE DE L'ATTENTION

Plusieurs études comportementales (Ansorge & Heumann, 2004; Folk & Remington, 1998, 1999, 2006; Folk et al., 1992, 1994; Lamy et al., 2004, Expériences

1-2; Remington et al., 1992, 2001) et en imagerie cérébrale (Serences et al., 2005) ont démontré que lors de la capture contingente de l'attention, un déplacement de l'attention visuospatiale vers la position de l'item possédant une caractéristique pertinente à la tâche en cours semblait survenir. Cependant, lorsque la cible devait faire l'objet d'une sélection non spatiale, deux études ont observé une capture contingente de l'attention par un distracteur présenté hors du foyer attentionnel qui perdurait jusqu'à au moins 500 ms après l'apparition des distracteurs (Egeth et al., 2000; Lamy et al., 2004, Expérience 3). Étant donné qu'il a été établi que des coûts associés au temps alloué au traitement des distracteurs portant une caractéristique cible pouvaient expliquer un effet de capture contingente même en l'absence d'un déplacement de l'attention visuospatiale (Ghorashi et al., 2003), cela laissait présager qu'un patron d'interférence plus complexe aurait pu être en cause dans ce cas.

Toutefois, dans les deux premières études, des données ont été présentées qui appuient l'hypothèse d'un déploiement de l'attention vers la position d'un distracteur portant la couleur cible, mais non d'un distracteur d'une autre couleur, pour expliquer l'effet comportemental de capture contingente de l'attention, même dans un paradigme où la cible n'est pas sélectionnée selon sa position spatiale. La troisième étude a répliqué ce résultat alors que la cible était définie par un attribut conceptuel, la catégorie alphanumérique. En effet, dans l'Article 1, un décours temporel présentant une forte interférence d'un distracteur périphérique présentant l'attribut cible a été enregistrée peu de temps après sa présentation, et la performance à la cible est retournée au niveau de base environ 350 ms plus tard. Ce résultat suggère que, d'une part, l'interférence s'est produite à un niveau de traitement relativement précoce, puisqu'elle était présente dès l'apparition du distracteur, et d'autre part, que l'attention n'a peu ou pas été engagée à la position du distracteur capturant l'attention, puisqu'elle s'est résorbée relativement rapidement. Les Articles 2 et 3, par l'enregistrement d'une composante des PLE associée au déploiement de l'attention visuospatiale, la N2pc, en réponse à des distracteurs porteurs de la propriété cible, ont confirmé l'interprétation visuospatiale de la capture contingente de l'attention. Quelques études employant également la N2pc comme indice du déploiement de l'attention visuospatiale ont depuis corroboré ce résultat, dans le cadre de paradigmes d'indiçage spatial modifié (Eimer & Kiss, 2008; Lien, Ruthruff, Goodin, & Remington, 2008) et de recherche visuelle (Kiss, Jolicoeur, Dell'Acqua, & Eimer, 2008), toujours avec des propriétés de bas niveau (apparition soudaine, couleur, forme).

De plus, en variant la similarité entre la cible et les distracteurs sur une autre dimension que celle qui définissait l'identité de la cible, l'Expérience 2 de l'Article 2 a permis d'évaluer un autre déterminant de la capture contingente de l'attention. En effet, les résultats ont montré que bien que la capture visuospatiale de l'attention était contingente seulement à la propriété définissant la cible (dans ce cas, la couleur), la similarité entre les distracteurs et la cible quant à une autre dimension (la catégorie) pouvait avoir un effet sur le temps alloué à leur traitement, tel qu'indiqué par une plus longue N2pc, mais seulement à la condition qu'ils possèdent également la propriété cible, et donc que l'attention soit déjà portée sur eux. Ce résultat est cohérent avec une étude de Remington et Folk (2001), qui ont trouvé que lorsque l'attention était orientée vers la position d'un distracteur à cause d'une capture contingente de l'attention (i.e., cette position avait été indicée par un indice possédant la caractéristique qui permettait de localiser la cible, par exemple, la couleur), le traitement de ce distracteur était limité à la propriété qui était pertinente à la tâche (i.e., la propriété sur laquelle reposait la réponse à la cible, par exemple, l'orientation).

Il est également intéressant de remarquer qu'en aucun cas, dans les deux articles utilisant les PLE (Articles 2 et 3), un distracteur semble avoir généré de SPCN (*sustained posterior controlateral negativity*). La SPCN est une composante négative latéralisée du côté controlatéral à un stimulus d'intérêt, calculée de façon analogue à la N2pc, qui reflète l'encodage en mémoire visuelle à court terme du stimulus en question (Jolicoeur, Brisson, & Robitaille, 2008; Klaver, Talsma, Wijers, Heinze, & Mulder, 1999; Vogel & Machizawa, 2004). Bien que cette composante n'ait pas été étudiée de façon formelle dans les présentes études, le fait qu'il n'y ait aucun indice de sa présence, même lorsque les distracteurs périphériques étaient très semblables à la cible de par leur catégorie, suggère fortement que les participants ont réussi à interrompre le traitement des distracteurs et d'en désengager leur attention rapidement lorsqu'elle avait été capturée.

Le rôle des mécanismes exogènes et endogènes dans la capture contingente de l'attention

L'hypothèse de capture pure avec désengagement rapide proposée par Theeuwes et al. (2000) a suggéré que tous les singletons avaient la capacité de capturer l'attention visuospatiale, mais que les contrôles attentionnels descendants permettaient un désengagement rapide de l'attention de la position du singleton distracteur si celui-ci ne possédait pas de caractéristique pertinente à la tâche. Bien que de nombreuses études employant des méthodes comportementales et d'imagerie cérébrale ont démontré une absence de capture par des singletons saillants mais non pertinents même à de courts SOA (e.g., Egeth et al., 2000; Folk et al., 2002; Lamy et al., 2004; Serences et al., 2005), la résolution temporelle de ces techniques ne permettait pas d'écarter avec certitude l'interprétation de Theeuwes et al. (2000).

Toutes les expériences présentées dans cette thèse appuient l'hypothèse selon laquelle une correspondance entre les contrôles attentionnels descendants et les propriétés ascendantes des stimuli est nécessaire pour provoquer la capture de l'attention, contrairement à la théorie de capture pure avec désengagement rapide proposée par Theeuwes et al. (2000). La première étude a apporté une preuve supplémentaire qu'un item possédant une caractéristique cible n'a pas besoin d'être un singleton pour capturer l'attention. Dans la seconde étude, l'emploi des PLE, qui ont l'avantage d'une excellente résolution temporelle, a révélé que seule la présence d'une caractéristique pertinente à la tâche générait un déploiement de l'attention visuospatiale vers la périphérie. Qui plus est, dans la troisième étude, le même résultat a été obtenu avec un ensemble de stimuli dans lequel les cibles et les distracteurs possédaient les mêmes caractéristiques de bas niveau. Ils ne pouvaient donc pas différer quant à leur saillance ascendante, ni sensorielle, ni perceptuelle. L'ensemble de la thèse souligne donc le rôle crucial des mécanismes endogènes, soit l'implémentation de contrôles attentionnels descendants, dans la capture attentionnelle, du moins dans les cas où de tels contrôles sont nécessaires pour effectuer la tâche (voir Turatto & Galfano, 2000, 2001, pour une interprétation de la capture attentionnelle en l'absence de contrôles attentionnels, dans une tâche requérant un mode de recherche sériel).

Toutefois, il est important de mentionner que la capture contingente de l'attention ne dépend pas seulement des mécanismes endogènes, mais qu'elle résulte bel et bien d'une interaction entre ceux-ci et les mécanismes exogènes, puisque, comme le soutenaient Folk et al. (1992, 1993), une fois les contrôles attentionnels mis en place, la réponse attentionnelle dépend uniquement de la stimulation. Ainsi, dans toutes les expériences présentées ici, le déploiement de l'attention vers la position d'un distracteur périphérique ne pouvait être qu'involontaire. En effet, les participants étaient avertis que des distracteurs périphériques apparaitraient, mais qu'ils devaient tenter de les ignorer, puisque la cible serait toujours présentée au centre et que les distracteurs ne véhiculaient aucune information quant à l'identité de la cible.

LA CAPTURE CONTINGENTE À UNE PROPRIÉTÉ DE HAUT NIVEAU

Bien que la capacité des propriétés de bas niveau telles la couleur et l'orientation à guider l'attention ne fasse aucun doute, le pouvoir d'attributs conceptuels à faire de même était contestée (e.g., Wolfe & Horowitz, 2004)

Dans l'Expérience 2 de l'Article 2, il a été démontré que lorsqu'un distracteur capturant l'attention appartenait à la même catégorie alphanumérique que la cible, le traitement attentionnel dont il faisait l'objet était prolongé. Toutefois, cet attribut ne suffisait pas à capturer l'attention, puisque ce n'était pas l'attribut qui permettait de repérer la cible parmi l'ensemble de distracteurs dans lequel elle était intégrée.

Dans la troisième étude, la cible était définie en fonction de son appartenance à une catégorie alphanumérique, chiffre ou lettre. Ainsi, elle ne différait des items de la catégorie opposée que par sa valeur conceptuelle, les traits de bas niveaux étant équilibrés entre les deux catégories (particulièrement dans l'Expérience 4). Les résultats ont démontré un effet comportemental de capture par les items périphériques appartenant à la catégorie cible, mais non par les items de la catégorie opposée et ce, même s'ils étaient plus similaires, sur le plan des caractéristiques physiques, à la cible potentielle que le symbole distracteur auquel ils étaient opposés. Qui plus est, cet effet comportemental s'accompagnait d'un effet électrophysiologique démontrant que l'attention visuospatiale était déployée vers la position des distracteurs de catégorie cible. Ces résultats mènent à la conclusion qu'en effet, des contrôles attentionnels descendants peuvent être implémentés en faveur de la catégorie alphanumérique, et qu'ils guident l'attention par des mécanismes similaires à ceux qui sont à l'œuvre pour des propriétés de plus bas niveau.

Il est à noter que la catégorie alphanumérique constitue une classification qui a fait l'objet d'un apprentissage extensif, du moins dans notre société occidentale, francophone et/ou anglophone. Il est donc impossible de généraliser à d'autres attributs conceptuels la conclusion que la capture peut-être contingente à la catégorie alphanumérique, à partir des présents résultats. Il serait donc intéressant d'explorer l'éventuelle implémentation de contrôles attentionnels descendants en faveur d'autres propriétés complexes.

COMMENT SONT IMPLÉMENTÉS LES CONTRÔLES ATTENTIONNELS DESCENDANTS?

À la suite des études constituant cette thèse, une question se pose : comment sont implémentés les contrôles attentionnels descendants? Plus spécifiquement, en quoi consistent les contrôles attentionnels descendants, et comment sont-il mis en place, maintenus, et recrutés lors de la présentation de stimuli?

Certains auteurs ont proposé qu'un modèle de la cible était enregistré en mémoire de travail, et biaisait le traitement des stimuli entrants (Desimone & Duncan, 1995; Downing, 2000; Pratt & Hommel, 2003). Selon eux, l'objet en entier serait ainsi stocké, et les items lui ressemblant quant à l'une ou l'autre de ses caractéristiques, et non seulement la caractéristique permettant de le définir comme cible, seraient favorisés.

D'autre part, le modèle de filtre à l'entrée (*input filtering model* : Di Lollo, Kawahara, Zuvic, & Visser, 2001), postule que les contrôles attentionnels descendants prennent la forme d'un filtre en faveur de la caractéristique cible uniquement (bien que si la caractéristique cible est une conjonction de traits, comme un objet en trois dimensions ou une lettre spécifique, cet ensemble complexe de caractéristiques peut faire l'objet d'un filtre). Le système cognitif est alors configuré de façon à traiter toute information qui correspond à ce filtre de façon optimale. Ainsi, si un stimulus autre que la cible possède cette caractéristique, il sera automatiquement pris en charge par le système cognitif comme s'il était une cible, étant donné que celui-ci est configuré pour le détecter et le traiter de façon très efficace. À l'opposé, un item qui ne présente pas la caractéristique cible ne sera pas privilégié par le système cognitif, puisque celui-ci n'est pas configuré pour l'accueillir. Si jamais un tel stimulus s'avérait pertinent, il serait traité plus lentement, moins efficacement, ou alors un peu plus tard, après que le système se soit reconfiguré pour y faire face.

Le problème avec ces deux modèles à l'égard des présents résultats est qu'ils postulent tous deux que les contrôles sont basés sur des représentations physiques, l'un d'un objet complet, et l'autre, soit d'une caractéristique spécifique, ou d'un ensemble de caractéristiques, dépendamment des demandes de la tâche. Toutefois, aucun des deux ne discute la possibilité qu'un attribut conceptuel, comme la catégorie, puisse agir à titre de modèle ou de filtre. En effet, même si les deux modèles admettent qu'un objet complexe tel une lettre puisse faire office de contrôle attentionnel, il est difficile de concevoir que tous les items d'une catégorie comme les lettres soient maintenus en même temps en mémoire de travail, par exemple. Ainsi, il faudrait postuler soit que les signaux de contrôle attentionnel proviennent, ou peuvent provenir d'aires prenant en charge des représentations plus complexes, d'ordre conceptuel, soit que la capture par la valeur conceptuelle relève de mécanismes différents. Par exemple, il se pourrait que les stimuli qui capturent l'attention en vertu de leur valeur conceptuelle soient analysés plus en profondeur avant que l'attention ne soit déployée vers leur position. Par exemple, plus d'information pourrait être acquise à leur sujet, de façon à les catégoriser ou à les identifier avant de déterminer si oui ou non ils correspondent à la propriété pertinente. L'observation de la négativité reliée aux caractères (*character related negativity*) dans les Expériences 2, 3, et 4 de l'Article 3, absente dans les Expériences de l'Article 2 dans lesquelles la caractéristique cible était la couleur, suggère qu'en effet une étape de traitement supplémentaire pourrait être effectuée dans le cas de la capture contingente à la catégorie. Par contre, la composante analogue étudiée par Hopf et ses collègues (Hopf, Boelmans, Schoenfeld, Luck, & Heinze, 2004) était générée dans un paradigme où seules des caractéristiques physiques, de bas niveau (la couleur et l'orientation) étaient en jeu, mais où l'ensemble de stimuli était assez complexe, puisqu'il comprenait de nombreux items similaires les uns aux autres. Cette étape de traitement pourrait donc refléter la plus grande difficulté à repérer la caractéristique cible, que ce soit à cause de sa propre complexité ou de celle de la scène visuelle.

Une autre question d'intérêt concerne la façon dont les contrôles attentionnels sont maintenus et activés. Une piste de réponse est apportée par Brisson, Leblanc et Jolicoeur (2009), qui ont observé, dans le cadre d'un paradigme de double tâche (période réfractaire psychologique) que le déploiement de l'attention visuospatiale vers un distracteur de couleur cible était supprimé si les ressources de l'attention centrale étaient engagées dans une tâche concurrente. Ceci suggère que l'attention centrale joue un rôle dans la capture contingente de l'attention, au-delà de l'établissement des contrôles attentionnels, puisque les participants dans cette étude, comme dans les études présentées ici, recherchaient la même couleur cible pendant toute la session expérimentale. Toutefois, il est impossible, sur la base de ces résultats, de déterminer si l'indisponibilité des ressources centrales a entraîné la désactivation temporaire des contrôles attentionnels en faveur de la couleur cible, où si elle a empêché le déploiement de l'attention visuospatiale vers la position du distracteur de couleur cible, malgré qu'il ait pu être repéré par le système attentionnel.

En conclusion, grâce aux trois études qui constituent cette thèse, j'ai démontré que la présence d'une caractéristique pertinente pour le choix d'un comportement à adopter est nécessaire et suffisante pour guider l'attention visuospatiale de façon involontaire vers la position de cette caractéristique. Ceci est vrai même si cette caractéristique ne produit pas un signal ascendant plus fort que les autres éléments d'une scène visuelle, c'est-à-dire lorsque tous les items sont équilibrés sur les plans sensoriel et perceptuel (e.g., luminance, traits de bas niveau) ainsi que contextuel (e.g., fréquence de présentation sur une longue période), ou requiert une catégorisation des items pour être repérée.

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