Université de Montréal

Étude électrophysiologique de l'impact de la couleur dans le déploiement attentionnel

par

Vincent Jetté Pomerleau

Département de Psychologie
Faculté des arts et des sciences

Mémoire présenté à la faculté de Psychologie
En vue de l'obtention du grade de maîtrise (M.Sc.)
En psychologie

Janvier, 2014

Université de Montréal
Faculté des Arts et des Sciences

Ce mémoire intitulé :
Étude électrophysiologique de l'impact de la couleur dans le déploiement attentionnel

Présenté par :
Vincent Jetté Pomerleau

a été évalué par un jury composé des personnes suivantes :

Frédéric Gosselin, président-rapporteur
Pierre Jolicoeur, directeur de recherche
Marc Schoenwiesner, membre du jury

Résumé :

L'influence de la couleur dans les mécanismes perceptuels et attentionnels a été étudiée. Quatre couleurs (le rouge, le vert, le bleu et le jaune) ont été calibrées individuellement à travers la technique *heterochromatic flicker photometry*. Suivant cela, les participants ont déployé leur attention à une cible (un cercle de couleur avec une ligne orientée). Les données électrophysiologiques ont été enregistrées pendant que les sujets performaient la tâche de recherche visuelle, et les analyses ont été basées sur les potentiels évoqués (PÉs). Trois composantes des PÉs ont été examinées : la posterior contralateral positivity (Ppc); la N2pc, reflétant le déploiement de l'attention visuo-spatiale et la temporal and contralateral positivity (Ptc). Des conditions dans lesquelles la cible était bleu ou rouge, lorsque comparées à des conditions avec une cible jaune ou verte suscitaient une N2pc plus précoce. Une amplitude plus élevée est aussi observée pour les cibles rouges pour les composantes Ppc et Ptc, reflétant une sélectivité pré-attentionelle. Ces résultats suggèrent de la prudence dans l'interprétation de données comparant des cibles de différentes couleurs dans des tâches de PÉs, et ce même lorsque les couleurs sont équiluminantes.

Mots-clés : Attention visuo-spatiale, potentiels évoqués, Clignement attentionnel, N2pc, Ppc, Ptc, heterochromatic flicker photometry

Abstract :

We investigated how target color affected behavioral and electrophysiological results in a visual search task. Perceptual and attentional mechanisms were tracked using the N2pc component of the event-related potential and other lateralized components. Four colors (red, green, blue, or yellow) were calibrated for each participant for luminance through heterochromatic flicker photometry and equated to the luminance of grey distractors. Each visual display contained 10 circles, 1 colored and 9 grey, each of which contained an oriented line segment. The task required deploying attention to the colored circle, which was either in the left or right visual hemifield. Three lateralized ERP components relative to the side of the lateral colored circle were examined: a posterior contralateral positivity (Ppc) prior to N2pc, the N2pc, reflecting the deployment of visual spatial attention, and a temporal and contralateral positivity (Ptc) following N2pc. Red or blue stimuli, as compared to green or yellow, had an earlier N2pc. Both the Ppc and Ptc had higher amplitudes to red stimuli, suggesting particular selectivity for red. The results suggest that attention may be deployed to red and blue more quickly than to other colors and suggests special caution when designing ERP experiments involving stimuli in different colors, even when all colors are equiluminant.

Keywords : Visual-spatial attention, event-related potentials, Attentional Blink, N2pc, Ppc, Ptc, heterochromatic flicker photometry

Table des matières

Table des tableaux

Table des illustrations

Liste des abréviations:

AB : Attentional blink
ANOVA : Analysis of variance
CA : clignement attentionnel
EEG : Electroencephalographam
EEG : Électroencéphalographique
ERP : Event-related potentials
MFP : Multiframe procedure
MS : millesecondes
MS : milliseconds
N2pc : Negative 200 posterior contralateral
PÉ : Potentiels évoqués
Ppc : Positive posterior contralateral
Ptc : Positive posterior contralateral
RGB : Red green blue
RT : Response times
RVB : Rouge vert bleu
TR : Temps de réponse
μV : microvolts

Remerciements

Pour le soutien financier, j'aimerais tout d'abord remercier mon directeur, la faculté des études supérieures, le Conseil de recherches en sciences naturelles et en génie du Canada (CRSNG) et le Fonds québécois en recherche naturelles et technologies.

Pour son support, les consultations, les réunions de laboratoire et les multiples corrections, j'aimerais grandement remercier mon directeur, le Docteur Pierre Jolicoeur. Par la même occasion, j'aimerais souligner l'importance de tous mes collaborateurs directs : Ulysse Fortier-Gauthier, Isabelle Corriveau, Roberto Dell'Acqua, Pia Amping et Christine Lefebvre; et indirects : Mercédès Aubin, Kristelle Alunni, Manon Maheux, Patrick Bermudez, Sébrina Aubin, Sophie Nolden, Stephan Grimault, Brandi Drisdelle et Avital Cherniawsky sans qui ce travail n'aurait pas pu être réalisé.

For handling my daily ups and downs, for being there all the time when I need it, and just for being the way he is, I wish to thank my love, Fernando. You supported me in many ways that you don't even realize.

Pour leur support, je remercie ma famille, particulièrement ma mère, sans qui je ne me serais jamais rendu ici et mon frère, le meilleur papa du monde, qui bien avant ce travail m'a donné un titre indélébile, celui de parrain. Merci.

Pour avoir été là, j'aimerais remercier Arnaud Demoustier, confident, psychologue et âme sœur. Également, j'aimerais remercier tous mes amis, particulièrement, Alexandra, Stéphanie, Nicholas et Julien.

Introduction

Position du problème

Deux théories d'analyse de la couleur ont été en opposition durant plusieurs années. Historiquement, la première est la théorie trichromatique de Young-Helmotz. Celle-ci repose sur un système de 3 récepteurs de sensibilité spectrale différente : les cônes bleus, verts et rouges, couvrant l'ensemble du spectre des couleurs visibles (Baylor, Nunn, & Schnapf, 1987; Buchsbaum & Gottschalk, 1983). Pour palier ce qui semblait être des inconsistances dans la théorie trichromatique, une seconde théorie, celle des processus opposés a été élaborée (Buchsbaum & Gottschalk, 1983). Celle-ci fait appel à des récepteurs répondant de façon opposée à des longueurs d'onde différentes : les neurones opposés du noyau géniculé latéral. Ces neurones génèrent donc un influx seulement pour une des couleurs présente dans son champ récepteur. Les couleurs en opposition sont: le bleu et le jaune, le rouge et le vert ainsi que le blanc et le noir. On sait aujourd'hui que les deux théories sont exactes et reflètent des mécanismes en œuvre soit en périphérie (théorie trichromatique) ou plus centraux (théorie des processus opposés) (De Valois, Abramov, & Jacobs, 1966).

En psychologie cognitive, la couleur est connue pour être un indice efficace pour la sélection attentionnelle (Clark, 1969; Posner, 1980; Von Wright, 1972). Une telle sélection est pertinente pour éviter la perte d'informations, puisque les mécanismes attentionnels ou de mémoire ne peuvent que traiter ou contenir un nombre limité d'objets simultanément (Cowan, 2001; Sperling, 1960). De plus, la littérature suggère que les mécanismes de l'attention visuo-spatiale traitent les items de façon sérielle (individuellement ou en petits groupes) à un moment dans le système visuel de façon à pouvoir les identifier plus en détail (Sperling, 1960; Treisman & Gelade, 1980).

La couleur est souvent utilisée dans des études en attention visuo-spatiale. Dans la plupart de ces études, la couleur permet d'identifier des stimuli en tant que cible ou distracteur. La prochaine section a pour but d'orienter le lecteur avec quelques études clés dans lesquels la couleur est un facteur expérimental important. Ce survol n'est pas une revue complète des thèmes de l'attention et de la couleur (à ce sujet, voire Carter, 1982; Treisman & Gelade, 1980; Wolfe, 1994).

Deux études récentes évaluent la contribution de la couleur à l'attention visuo-spatiale. La première étudie la contribution de la couleur au traitement du mouvement dans la sélection automatique de cibles (Tchernikov & Fallah, 2010). Les auteurs ont comparé des saccades oculaires à des agrégats de points de couleurs différentes. Les points contenus dans les agrégats étaient tous de même couleur et équiluminants (rouge, vert, jaune ou bleu). L'expérience 1 mesurait la rapidité et la direction des saccades selon les différentes couleurs, pour un seul agrégat, après qu'un point de fixation disparaisse. L'expérience 2 comparait les couleurs en observant la sélection automatique de cibles à travers un choix forcé entre deux agrégats de points de deux différentes couleurs allant dans des directions opposées. Ensemble, ces expériences démontrent une hiérarchie des couleurs dans laquelle un biais de sélection des saccades va du rouge (le plus élevé), au vert, au jaune et puis au bleu (le plus faible).

Un second article évalue les temps de réaction (TRs) à différentes cibles de couleurs désaturées (Lindsey et al., 2010). Des cibles désaturées étaient placées parmi des distracteurs saturés ou blancs. Pour minimiser les différences dans l'apparence des couleurs, les auteurs ont choisi des cibles désaturées (30cd/m^2) qui se trouvent au centre d'une droite entre les distracteurs saturés (12 cd/m^2) et blancs (60cd/m^2) dans l'espace de couleur CIE L*ab. Ces couleurs ont de plus été testées dans deux expériences contrôle, l'une impliquant un appariement hétérochromatique (heterochromatic matching) et une seconde, basée sur la différence maximale de ressemblance (Maximum Likelihood Difference Scaling). Les couleurs utilisées étaient : rouge, vert, bleu et orange, toutes désaturées. Les auteurs trouvent des TRs plus rapides pour les couleurs chaudes (rouge) et plus lents pour les couleurs plus froides (bleu-mauve). Les graphiques rapportent des TRs plus rapides pour le jaune que le vert, mais ces résultats ne sont pas discutés dans l'article.

Il ressort de ces études qu'il semble y avoir un biais attentionnel pour certaines couleurs par rapport à d'autres. Jusqu'à présent, seulement des TRs ont été rapportés. Dans ce projet, la technique des potentiels évoqués (PÉs) sera utilisée comme outil d'investigation dans le déploiement attentionnel à des cibles de différentes couleurs équiluminantes. Notre but premier sera ainsi de déterminer si des mécanismes neuronaux attentionnels pourraient refléter ce biais. Dans cette étude, les couleurs qui seront choisies seront le rouge, le vert, le bleu et le jaune et les composantes à l'étude seront la N2pc, la Ppc et la Ptc.

Contexte théorique

La N2pc

La N2pc est une composante des PÉs observable en soustrayant l'activité électrique des électrodes ipsilatérales à l'activité électrique aux électrodes controlatérales à l’hémichamp visuel d’un objet dans le focus attentionnel. La N2pc est enregistrée à des sites postérieurs du scalp, avec une activité maximale aux sites PO7/PO8. La latence de la N2pc est dans l’intervalle des composantes N2, entre 180 et 250 ms suivant la présentation du stimulus (Brisson & Jolicoeur, 2007; Luck & Hillyard, 1994; Robitaille & Jolicoeur, 2006). Luck and Hillyard (1994) soutiennent que la N2pc reflète un filtrage spatial des distracteurs, et Eimer (1996) ainsi que Mazza (Mazza, Turatto, & Caramazza, 2009a, 2009b) soutiennent qu’elle reflète plutôt une amplification de la réponse neuronale à la cible.

La couleur est souvent utilisée dans les expériences qui mesurent la N2pc (Eimer, 1996; Hickey, Di Lollo, & McDonald, 2009). Ces études ont des conditions dans lesquelles la cible est d’une couleur et les distracteurs d’une autre, tout en s’assurant d’avoir des stimuli équiluminants. Également, un nombre égal de participants ou d’essais avec une cible de chaque couleur est effectué avant de tout moyenner. L’effet direct des couleurs a été très peu étudié en tant que tel. Lorsqu’il l’est, les études abordent généralement des questions de recherche non reliées à la chromaticité (par exemple : l’effet du langage sur la détection/la disparité entre cible et distracteur). Il y a donc une quasi-absence de tests de latence et d’amplitude de la N2pc faits entre les différentes couleurs expérimentales (Liu et al., 2009; Regier & Kay, 2009).

Un article récent utilise la N2pc afin d’évaluer le rôle de la disparité physique de couleurs entre cibles et distracteurs (Zhao et al., 2011). Dans leur étude, les auteurs modulent la différence physique entre cible et distracteur en observant les effets sur la composante. Les auteurs comparent des conditions dans lesquelles la disparité du distracteur est élevée (distracteur bleu pâle/ cible bleu foncé) et une condition dans laquelle elle est faible (distracteur bleu moyen/ cible bleu foncé) en manipulant les valeurs RVB (rouge vert bleu) des couleurs des stimuli. Tout au long de l'expérience, les stimuli utilisés sont équiluminants. Les participants doivent trouver la cible (une croix) qui est différente des autres, et décider si celle-ci a un trait inférieur égal ou non au trait supérieur. Un effet principal de disparité de couleur est rapporté, l'amplitude moyenne de la condition avec haute disparité est plus négative que la condition de faible disparité. Un effet marginal de latence est également rapporté, la N2pc reliée à la condition de faible disparité étant plus retardée que N2pc de la condition de disparité élevée.

La Ppc

La *posterior contralateral positivity* (Ppc) est une composante latéralisée, apparaissant avant la N2pc, entre150 à 200 ms post stimulus. L'amplitude moyenne de la Ppc et sa latence ne dépendent pas de l'intervalle de temps entre les stimuli et est suscitée autant par des distracteurs que des cibles (Corriveau et al., 2012). La composante semble refléter la représentation d'un champ visuel débalancé, lorsque par exemple un item saillant est présenté d'un seul côté de l'hémichamp visuel.

La Ptc

La Ptc, pour *positive temporal contralateral* est une composante observable controlatéralement à un item dans le focus attentionnel. La Ptc est présente entre 290 et 340 ms post-stimulus. Certains auteurs affirment que la composante reflète une interférence locale résultant de la proximité spatiale entre cibles et distracteurs (Hilimire, Mounts, Parks, & Corballis, 2009). L'amplitude de la composante augmente généralement à mesure que la distance cible-distracteur diminue (Hilimire, et al., 2009). Cette plus grande amplitude reflète probablement une inhibition après le déploiement attentionnel dans le but d'isoler une cible une fois celle-ci identifiée (Hilimire, Mounts, Parks, & Corballis, 2011). La composante ne varie pas selon la saillance entre la cible et les distracteurs (tel que manipulée par la saturation des couleurs des deux items) (Hilimire, Mounts, Parks, & Corballis, 2010).

Objectif particulier ou hypothèse

Cette étude vise à clarifier le rôle de la couleur dans le déploiement attentionnel par des mesures électrophysiologiques. Ceci permettra de mieux comprendre les résultats dans la littérature ainsi que de suggérer des mécanismes cognitifs impliqués. En combinant les résultats expérimentaux comportementaux et électrophysiologiques, deux hypothèses peuvent être émises. Premièrement, la N2pc, devrait refléter une hiérarchie chromatique dans le déploiement attentionnel à des cibles de différentes couleurs. Cette hiérarchie pourra être observée sur la N2pc par une amplitude plus négative et/ou des latences différentes en réaction à différentes couleurs (Lindsey, et al., 2010; Tchernikov & Fallah, 2010; Zhao, et al., 2011). La hiérarchie attendue est la suivante : rouge, vert, jaune, bleu. Très peu d'études évaluent le rôle ou même l'existence des composantes Ppc et Ptc. Les expériences précédentes avec la Ppc indique que celle-ci reflète la représentation d'un champ visuel débalancé (Corriveau, et al., 2012). Puisqu'un biais attentionnel devrait créer un tel débalancement, une Ppc plus positive pour les couleurs générant une réponse attentionnelle plus forte, comme le rouge, est attendue. La Ptc, représentant un processus d'inhibition des distracteurs physiquement proches dans la représentation visuelle devrait avoir aussi une plus grande amplitude pour les couleurs avec plus de saillance comme le rouge. Ceci permettrait une meilleure inhibition des couleurs les plus saillantes.

Dans le but de maximiser une perception de couleur équiluminantes pour chaque participant, il est nécessaire de calibrer individuellement les couleurs pour chaque sujet. Les résultats obtenus devront aussi écarter la possibilité de variables médiatrices, comme la discriminabilité. Cette dernière sera évaluée à travers deux expériences contrôle.

Méthodologie

Calibration

Stimuli

Les stimuli pour la tâche de calibration consistent en 10 cercles pleins (ou disque) contenant chacun des teintes différentes de la même couleur, tel qu'illustrés dans la Figure 2a. Chaque cercle a un diamètre de 1.25 degré d'angle visuel. Les 10 cercles sont tous soit rouges, verts, jaunes ou bleus dépendant du bloc expérimental. Ces cercles sont disposés autour d'une croix, pour former un grand cercle de 3 degrés d'angle visuel. La couleur de chacun des cercles est ajustée par une adaptation d'une procédure nommée *heterochromatic flicker photometry*.

Procédure

La technique *heterochromatic flicker photometry* consiste en une alternance de deux sources de couleur différentes en une même position spatiale et permet de contrôler pour les différences individuelles de luminance entre différentes couleurs (Bone & Landrum, 2004; Walsh, 1953). Les sujets doivent minimiser leur perception de clignotement en modifiant les valeurs de luminance d'une des deux couleurs alternantes.

La fréquence de l’alternance doit être assez basse pour percevoir un clignotement, mais assez élevée pour percevoir une fusion des deux couleurs (la fréquence qui sera utilisée sera de 15 Hertz). La calibration se termine lorsque la perception de clignotement est minimisée.

La technique générale a été modifiée de deux façons majeures (figures 2ab). Premièrement, des cercles en alternance seront seulement présentés en périphérie du champ visuel. Cette mesure permet d’avoir des stimuli présentés à la même excentricité que dans l’expérience électrophysiologique (expérience 1) et les expériences contrôles (expérience 2a et 2b). Les participants doivent initialement garder leur attention au point de fixation, puis, advenant une impossibilité de décider lequel des cercles affichera le moins de clignotement, fixer directement les cercles. La seconde modification consiste en une présentation de plusieurs cercles simultanément et en faisant varier la valeur de luminance des cercles. La technique classique implique que tous les cercles aient la même teinte. Dans la technique modifiée, chaque cercle prend une teinte unique (figure 2a). Dépendant de la couleur du cercle, une différente valeur RVB sera présentée dans chaque cercle. Ainsi, en partant aléatoirement de l’un des dix cercles, une valeur précise est ajoutée de façon cumulative à la luminance de chaque cercle de façon horaire à quatre reprises. Du même cercle initial, mais de façon antihoraire, la même valeur sera soustraite à la valeur initiale à 5 reprises, créant ainsi dix cercles dont la luminance diffère de façon graduelle de cercle en cercle. La valeur ajoutée ou soustraite dépend de la couleur et de l’étape d’ajustement. De façon générale, à mesure que la calibration progresse pour une couleur donnée, les saut de valeur ajoutée ou soustraite de luminance diminue, passant de 20 à 10 puis 5. Ainsi, pour la condition où les cercles seront tous rouges, une valeur de R sera différente dans chaque cercle, mais les valeurs de V et de B sont les mêmes. Une procédure similaire sera appliquée pour la valeur V dans la condition verte, la valeur B dans la condition bleue et les valeurs V et B dans la condition jaune. Après chaque réponse, les écarts entre les valeurs RVB entre les cercles diminuent, jusqu'à ce que seulement des différences minimes subsistent. Les différences entre chaque stimulus de couleur et le gris seront ainsi réduites au maximum. Chaque couleur est calibrée trois fois à travers quatre choix multiples forcés dans lesquels le sujet doit à chaque fois choisir parmi les dix cercles lequel présente la perception de clignotement la plus réduite.

Tâche électrophysiologique –Expérience 1

Stimuli

La présentation visuelle de la tâche électrophysiologique est similaire à celle de la tâche de calibration. Dix cercles sont présentés avec la même excentricité (figure 1). La principale différence par rapport à la calibration est la présence de trois types de stimuli : les stimuli de fond, les cibles et les leurres. Le stimulus de fond est un cercle formé d'une ligne grise et contient une barre grise sur fond noir avec 4 orientations possibles : verticale, horizontale, oblique vers la gauche ou la droite. Les couleurs prises par les cibles et les leurres sont les valeurs finales obtenues par la calibration et sont donc équiluminantes entre elles et au gris des stimuli de fond.

Procédure

Suivant la calibration, et avant le début de l'expérience, une barre avec une orientation spécifique (horizontale ou verticale, également divisée entre les sujets) est présentée à chaque participant. Cette barre permet la distinction entre deux types de stimuli, les cibles (cercles colorés contenant la barre d'orientation cible) et les leurres (cercles colorés avec une barre orientée non-cible). Des stimuli de fond occupent l'espace non pris par une cible ou un leurre. Chaque tableau de recherche contient soit une cible, soit un leurre, ainsi que 9 stimuli de fond.

Les participants commencent chaque essai en appuyant sur la barre d'espacement. Par la suite, une croix de fixation est présentée pendant 500 ms avant le début d'une série de présentations visuelles. Un tableau de recherche contenant les dix cercles décrits plus-haut est ensuite présentée pendant 200 ms, puis est suivi d'une croix de fixation pendant 600±100 ms. La tâche est une recherche visuelle. Les participants ont à trouver et compter le nombre de cibles (de 0 à 3) dans une succession de 6 tableaux de recherche. Après la présentation des six tableaux de recherche et croix de fixation, les participants indiquent par les lettres 'v', 'b', 'n' ou 'm' du clavier s'ils ont vu 0, 1, 2 ou 3 cibles. Cette procédure permet de multiples déploiements attentionnels avant une réponse se nomme MFP, de l'anglais *Multiframe Procedure.* Cette technique permet une diminution plus grande du bruit autour des composantes sans augmenter grandement le temps de l'acquisition des données. Une rétroaction par rapport au nombre de cibles indiquées est affichée pendant 500 ms. L'expérience contient 5 blocs de 80 essais pour un total de 400 essais de 6 déploiements attentionnels. Chaque participant effectue donc 2400 déploiements attentionnels.

Tâches contrôles –Expériences 2a et 2b

Certaines limitations nuisent aux conclusions de l'étude et demandent un contrôle supplémentaire. En effet, une possibilité de notre calibration est la création de couleurs qui ne sont pas toutes également discriminable du gris. Pour vérifier cette possibilité, deux expériences comportementales contrôles ont été crées. Ces tests évaluent la capacité à discriminer chaque couleur créée par la calibration par rapport au gris.

Stimuli

La présentation visuelle des expériences contrôle diffère des précédentes (Figure 10 ab (première tâche) 10 cd (seconde tâche)). Dans les deux expériences, seulement deux cercles au lieu de dix sont présentés. Les propriétés visuelles des stimuli (taille et distance du point de fixation) sont par contre les mêmes[1]. La principale différence entre la première et la seconde tâche est que les cercles sont vides dans la première et pleins dans la seconde. Pour les deux tâches, chaque cercle peut être une de 5 couleurs différentes, soit le gris ou l'une des 4 couleurs obtenues par la tâche de calibration.

Deux conditions de présentations visuelles différentes peuvent être affichées. Pour la condition *pareille*, les cercles seront de la même couleur, soit tous les deux gris, soit tous les deux d'une couleur obtenue par la calibration (figure 10a et 10c). Pour la condition *différente,* l'un des cercles sera gris et l'autre de l'une des quatre autres couleurs (figure 10b et 10d). Deux cercles de couleurs différentes ne sont pas présentés simultanément, puisque cela n'est pas similaire aux conditions de l'expérience en électrophysiologie. Bien que les deux conditions (pareille, différente) soient nécessaires

---

[1] Considérant la distribution différente des cônes dépendant de l'excentricité, ce dernier point est essentiel afin de calibrer et tester les couleurs sur une population similaire de cônes.

pour avoir une variabilité dans les réponses, la condition vitale pour cette expérience est la condition différente, qui évaluera la discriminabilité des couleurs par rapport au gris.

Procédure

Une croix de fixation est présentée pendant 500 ms à chaque essai. Après la croix, deux cercles sont présentés pendant 200 ms. Après cette présentation, les participants appuient sur “v” si les deux cercles présentés ont la même couleur, ou “b” si les deux cercles diffèrent. L’expérience a 455 essais, dont 70 compareront un cercle gris à un cercle de couleur pour un total de 280 comparaisons couleur-gris.

Color specific differences in attentional deployment for equiluminant pop-out colors: Evidence from lateralized potentials.

Vincent Jetté Pomerleau[1], Ulysse Fortier-Gauthier[1], Isabelle Corriveau[1], Roberto Dell'Acqua[2], & Pierre Jolicœur[1]

[1] *Université de Montréal, Montréal, Québec, Canada*
[2] *University of Padova, Padova, Italy*

RUNNING HEAD: Color specific differences in attentional deployment

Corresponding author:
Pierre Jolicœur
Département de Psychologie
Université de Montréal
C.P. 6128, succursale Centre-ville
Montréal QC H3C 3J7, Canada
Fax: (+1) 514-343-2285
Phone: (+1) 514-343-6511

AB: We investigated how target color affected behavioral and electrophysiological results in a visual search task. Perceptual and attentional mechanisms were tracked using the N2pc component of the event-related potential and other lateralized components. Four colors (red, green, blue, or yellow) were calibrated for each participant for luminance through heterochromatic flicker photometry and equated to the luminance of grey distractors. Each visual display contained 10 circles, 1 colored and 9 grey, each of which contained an oriented line segment. The task required deploying attention to the colored circle, which was either in the left or right visual hemifield. Three lateralized ERP components relative to the side of the lateral colored circle were examined: a posterior contralateral positivity (Ppc) prior to N2pc, the N2pc, reflecting the deployment of visual spatial attention, and a temporal and contralateral positivity (Ptc) following N2pc. Red or blue stimuli, as compared to green or yellow, had an earlier N2pc. Both the Ppc and Ptc had higher amplitudes to red stimuli, suggesting particular selectivity for red. The results suggest that attention may be deployed to red and blue more quickly than to other colors and suggests special caution when designing ERP experiments involving stimuli in different colors, even when all colors are equiluminant.

Color is an effective cue for attentional selection and as such is often used in experiments probing attentional mechanisms (Bacon & Egeth, 1994; Clark, 1969; Jolicoeur, Brisson, & Robitaille, 2008; Posner, 1980; Von Wright, 1972; Woodman & Luck, 2003). Attentional selection enables us to concentrate our limited attentional resources on a subset of the visual information reaching the visual cortex. Selection is required to avoid the loss of relevant information at later stages of processing because higher-level visual areas can only process and/or store a finite number of relevant objects (Cowan, 2000; Dell'Acqua, Dux, Wyble, & Jolicoeur, 2012). Visual spatial attention mechanisms are believed to process visual items serially (whether individually or in small groups) at some point in the visual processing stream in order to be identified in more detail and to control further processing (Sperling, 1960; Treisman & Gelade, 1980).

Over the years, a lot of effort has been put in determining the physiological basis of color perception. One of the first major theories was the Young-Helmotz, or trichromatic theory. It is based on a 3 receptors system, each with its own spectral sensitivity: the short, middle and long wavelengths cones, covering the totality of the visible colors (Baylor, et al., 1987; Buchsbaum & Gottschalk, 1983). A second theory that was put forward was the opponent processes theory (Buchsbaum & Gottschalk, 1983). According to this theory, receptors with opposing responses are activated by different wavelength. These neurons respond only for one of two color present in its receptive field. The colors in opposition are : red and green, blue and yellow and black and white. It is now well known that both mechanisms reflect different processes, one being peripheral, to the retina (trichromatic theory), and the other, more central, in the lateral geniculate nucleus (opponent processes theory)(De Valois, et al., 1966).

Colors and visual spatial attention

Usually, colors are used as a discriminative tool for segregating visual targets from distractors. This section provides a brief overview of the results of a few key studies in which chromaticity was shown to have an experimental effect in attentional tasks. Additional discussion can be found in a number of more detailed studies (for which we suggest key studies e.g. Carter, 1982; Treisman & Gelade, 1980; Wolfe, 1994).

Two recent papers evaluate the contributions of color to visual spatial attention (see also Ansorge & Becker, 2013; Lennert, Cipriani, Jolicoeur, Cheyne, & Martinez-Trujillo, 2011, for additional evidence). The first study addresses the contribution of color to motion processing in automatic target selection (Tchernikov & Fallah, 2010). The authors measured smooth pursuit eye movements that occur spontaneously immediately following a saccade to a circular region containing dots moving coherently either left or right. The dots were red, green, blue, or yellow (with luminance equated across colors). In two experiments, pursuit movements were initiated earlier for red dots. In experiment 1, this was evaluated with one color at a time. The participant's task was to move their eyes in the general direction of the colored stimulus after the disappearance of a white fixation cross. In experiment 2, different colors were put in opposition and red tended to win over other colors (if two sets of dots moved in the region in different directions, the spontaneous pursuit movements were in the same direction as the moving red dots). Overall, a hierarchy of colors was found, from red (strongest), to green, to yellow, to blue (weakest).

A second paper also evaluated reaction times (RTs) to targets of different desaturated colors (Lindsey, et al., 2010). In this study, desaturated color targets (pink, green, blue, and orange) were placed in a visual display among white and saturated distractors. Participants had to indicate the presence or absence of a target on every trial. To minimize the magnitude of difference in color appearance, the authors chose desaturated targets ($30cd/m^2$) that laid at the midpoint of a line segment between saturated distractor ($12\ cd/m^2$), and white distractor ($60cd/m^2$) in CIE L*ab color space. Those colors were furthermore tested through two auxiliary experiments, the first involving direct heterochromatic matching, and the second based on Maximum Likelihood Difference Scaling. The authors found faster RTs for desaturated red than desaturated orange and green, and slower RTs for desaturated blue (red <orange<green<blue).

What can be retained from these studies is that there seems to be an attentional bias for some colors over others, favoring their selection by attention and hastening our response when they are target. So far, mostly RTs have been reported, but RTs effects are often coupled to observable electrophysiological effects (Brisson, Robitaille, & Jolicoeur, 2007; Mazza, et al., 2009a). Here we used event-related potentials (ERPs) as a way to monitor, millisecond-to-millisecond, the deployment of attention to colored targets. Our goal was to determine if, like visual search or spontaneous capture of smooth pursuit eye movements, the mechanisms that guide and engage attention reflected by the N2pc component of the ERP would show systematic variations as a function of stimulus color. We chose colors (red, green, blue, yellow) that are frequently used in visual search task (with and without electrophysiology) involving color. Our main interest was in the lateralized electrophysiological components known for their link to visual attention, namely the N2pc. However, we were also interested in two other lateralized components, one just before the N2pc, the Ppc (positivity posterior contralateral), and the other just after the N2pc, the Ptc (positivity temporal contralateral).

The N2pc

The N2pc is a lateralized ERP component that can be calculated by subtracting the electrical potentials measured at electrodes sites ipsilateral to a lateral attended object from the electrical potentials measured at electrode sites contralateral to that object. The N2pc is observed over the posterior scalp, with peak amplitude typically observed at or near electrodes PO7/PO8. As the name suggests, the latency of the N2pc is in the N2 time range, which is 180–280 ms following the onset of an attended stimulus (Brisson & Jolicoeur, 2007; Luck & Hillyard, 1994; Robitaille & Jolicoeur, 2006). Luck and Hillyard (1994) argued that the N2pc reflects spatial filtering of distractors, whereas Eimer (1996) and, more recently, Mazza and her colleagues (2009a, 2009b) argued that the N2pc reflects target enhancement.

It is no surprise that, much like in behavioral attentional studies; color is often used in ERP experiments involving the N2pc (Eimer, 1996; Hickey, et al., 2009). Studies usually report conditions in which the target and distractor are equiluminant to equate bottom-up effective intensity. Then, after making sure that an equal number of participants/trials are performed with each color, different color trials are averaged together. Typically, the direct effect of colors on the N2pc is not discussed, with possible differences assumed to have been equated across conditions. This approach is technically sound when there are no color-specific interactions, but has downplayed what appear to be quite substantial effects that are interesting in their own right. When experimenters do study the effect of colors on the N2pc, it is often with search questions unrelated to chromaticity (e.g., effect of language on detection/disparity between target and distractor). This results in a near absence of reports of N2pc latency or amplitude effects between colors (Liu, et al., 2009; Regier & Kay, 2009).

One pertinent paper regarding our research question evaluated the role of physical disparity between target and distractor items (Zhao, et al., 2011). In their study, the authors modulated the physical difference (through color in one condition) between target and distractors while observing the effect on the N2pc. They compared conditions in which the disparity from the distractor was high (distractor light blue, target dark blue) and a condition in which it was low (distractor medium blue, target dark blue), by manipulating the RGB values of the colors while maintaining them equiluminant. Participants were asked to find the stimulus (a cross) that differed in color and to decide whether the top or the lower segment of the vertical bar of the target was longer. A main effect of color disparity was found, with the mean amplitude of the N2pc in the high color disparity condition being larger (more negative) than the low-disparity condition. A marginal effect of latency was also found, with the N2pc related to low disparity being later than the high-disparity N2pc. Both ERP results dovetailed with the behavioral data in which the high disparity condition had faster RTs than the low disparity condition.

The Ppc

Rarely discussed, the posterior contralateral positivity (Ppc) is a lateralized component earlier than the N2pc, roughly from 150 to 200 ms post stimulus. In a study by Corriveau et al. (2012), neither the mean amplitude of the Ppc nor its latency depend on the lateral item status as target or distractor. This early-lateralized response appeared to reflect an attention driven spatial “attend-to-me” signal that arises in the waveforms of an unbalanced visual display containing a salient stimulus only on one side.

The Ptc

The Ptc is a *positive* component that can be observed over the *contralateral* hemisphere of the attended item. The Ptc was observed between 290 and 340 ms post stimulus in previous experiments. The label “*temporal”* follows the suggestion of Hilimire, Mounts, Parks, and Corballis (2009). However, while our component has the same approximate latency, and also follows the N2pc, it does not seem as anterior as the one reported by Hilimire et al., and thus it could reflect a different underlying process. Hilimire et al. (2009) suggested the Ptc might reflect local attentional competition resulting from the spatial proximity between a target and a salient distractor. The amplitude of the component generally becomes larger (more positive) as the physical separation between the target and a salient distractor decreases (Hilimire, et al., 2009). This modulation of Ptc amplitude could reflect distractor inhibition after initial attentional deployment (the N2pc), in order to isolate a target once it has been identified (Hilimire, et al., 2011). Their component did not vary with target-distractor saliency difference (manipulated through color saturation of the target or the salient distractor), in apparent contrast with ours (Hilimire, et al., 2010).

From previous ERP and behavioral experiments, we expected to see a difference in the N2pc amplitude and latency for colors that allow a better attentional deployment, possibly resulting in a color hierarchy (Tchernikov & Fallah, 2010; Zhao, et al., 2011). More precisely, we anticipated a shorter N2pc latency to red targets, based on the Tchernikov and Fallah (2010) results. However, Lindsey et al. (2010) only found an advantage for desaturated reds, and so the typical red stimuli used in most attention selection experiments may not be subject to the special effect for desaturated red. Predictions for other colors are even more difficult to make, given paucity of results and inconsistent results across studies.

Very few experiments explored the role or even the existence of the Ppc and Ptc. Previous experiments dealing with the Ppc component indicate that it reflects the representation of an unbalanced visual display (Corriveau, et al., 2012). Since color attentional bias should create an unbalanced display, we would expect a more positive Ppc for colors with a stronger attentional response, namely the red target compared to other targets. The Ptc reportedly representing inhibitory processing of close distractors could amplify in amplitude for colors with increased salience like red, since more inhibition should be required for more salient targets.

In most of our recent work we equated the luminance of colors using a specialized instrument (Minolta CS100 chromameter). We wondered, however, if individual differences luminance responses could produce small but systematic luminance differences that would bias attention to one or another of the colors. In order to minimize possible individual differences, we used a psychophysical luminance calibration procedure to equate luminance of the colors for each individual.

Furthermore, in order to determine if some colors were more or less discriminable from the background grey distractor stimuli used in all displays, we conducted two control experiments. These control experiments consisted in visual discrimination tasks that should not yield significant differences between colors if all colors are equally discriminable from the distractors. Given the color singletons to which attention was to be deployed were presented only with other grey stimuli, and the color differences across color stimuli and grey were large, one would expect to find a pop-out pattern of rapid and effortless search.

Experiment 1

The purpose of Experiment 1 was to determine if different colors would elicit different lateralized ERPs, and most particularly different N2pc waves, under conditions in which each color was presented on a neutral background of grey distractors. These are conditions that should minimize differences across colors, because colors were never in direct competition for selection with each other. They just had to be found among the neutral grey distractors. This is illustrated in Figure 1.

Insert Figure 1 about here

Method

Sixteen paid volunteers participated in Experiment 1. Three participants were rejected, two because of HEOG activity exceeding 25 μV on a 200 ms interval on more than 50% of trials, suggesting an eye movement towards the lateral target (see below) and one for an accuracy that was at or near chance (25%) in more than one condition. The remaining ERP participants (9 males and 4 females) had a mean age of 23.2 years (*S.E.* = 2.8, range 19–29). All 13 participants were neurologically normal undergraduates at the Université de Montréal and had normal color vision, and either normal or corrected-to-normal visual acuity.

Luminance calibration methodology

Stimuli

Stimuli for the calibration experiment consisted in two types of frames, each displaying simultaneously 10 numbered disks, as illustrated in Figure 2. The disks could be red, green, blue or yellow, depending of the trial block. Each disk of Figure 2a showed different shades of the same color, while all disks of Figure 2b were displayed with the same reference grey. Each disk had a diameter of 1.25° of visual angle and was placed 3° from a central fixation point, thus forming a circle of disks. Participants individually set luminance values through a variant of the heterochromatic flicker photometry technique, described next.

Insert Figure 2 about here

Procedure

In order to control for subtle individual differences in color perception, we used a variant of the heterochromatic flicker photometry technique (Bone & Landrum, 2004; Walsh, 1953). The heterochromatic flicker photometry technique uses the alternation of two colored stimuli at the same spatial position (we alternately presented the numbered disk presented on Figure 2a and 2b). Participants had to minimize their perception of flicker through luminance adjustment of one of the two colors while colors alternated. The rate (or frequency) of the alternation needs to be high enough in order to obtain a flicker but not so high that color fuse (we used a frequency of 15 Hz). Equal luminance between colors is obtained when the perception of flicker is minimized.

We modified the usual heterochromatic flicker photometry technique in two ways (see Figure 2). First, we only presented disks containing flickering colors to the periphery of the visual field. That allowed the presentation of stimuli at the same eccentricity as in the ERP and control experiments. Participants were instructed to pay attention to the disks while looking at a central fixation point. Only after doing this could participants directly look at the disks to make a final decision. The second modification from the original technique was in the luminance value of each circle. In our modified technique, each disk presented in periphery had a slightly different luminance (see Figure 2a), while only a single color is presented in the usual technique. Depending on the color of the circle (red, green, blue, or yellow), a different RGB value was displayed within each disk. From a random disk position, a precise value was added in a clockwise manner four times, and from the same random disk, the same value was subtracted five times in an anticlockwise manner. If disks were all red, then a different value of red was present in every disk while the green and blue component values stayed the same. The same applied for the green and the blue colors, while for the yellow, both red and green component values were modified with a common value and the blue component stayed constant.

The task of the participant was to choose which of the 10 numbered disks showed the least flicker. Participant's answer was recorded through the numeric keypad of a standard keyboard, key 1 corresponding to disk 1 and key 0 to disk 10. After each response, the RGB differences between circles were adjusted to represent a smaller range of RGB colors starting with stimulus chosen on the previous response, until only small (single-step: first 20, then 10, then 5) difference remained between each disks. By doing so, we selected the RGB values providing the least individual luminance difference perception for each color. Each one of the four colors was calibrated 3 times through 4 forced choice flickering frames. The mean of each RGB component for the 3 calibrations was used as the calibrated color.

Experiment 1 task

Stimuli

The visual display of a frame was very similar to the frames used in the calibration procedure, as illustrated in Figure 1. Ten circles were displayed, at the same distance from a fixation point as the calibration procedure. The only difference from the calibration frames was the existence of three types of stimuli: distractors, targets, and decoys. Distractors consisted of circles formed with a thin grey line, and containing a grey oriented line on a black background. Oriented lines could either be horizontal, vertical, or at ± 45° from vertical. Targets and decoys were also circles containing an oriented line, but instead of being grey, they were displayed in color. All colors including the grey were obtained from the calibration procedure and were therefore equiluminant.

Procedure

In the search task that followed the calibration procedure, targets were defined as any colored circle containing either a vertical line (half of the participants) or a horizontal line (the other half). Every visual search display contained a colored circle (a color singleton among grey distractors) containing a line that was either in the target or non-target orientation (one of the other three orientations). Each of the grey distractor circles also contained a line in one of the four possible orientations, chosen at random independently for each display.

Participants initiated every trial by pressing the spacebar. A fixation cross was displayed for 500 ms before the beginning of the trial. Six search displays, henceforth called frames, were then presented, one after the other. Each frame was visible for 200 ms followed by a fixation cross for 600±100 ms. Participants had to count the number of targets (from 0 to 3) in the sequence of six frames and report the count by button press at the end of the sequence. The letters ‘v’, ‘b’, ‘n’ or ‘m’ were used to respond 0, 1, 2, or 3 targets, using the middle and index fingers of the left hand (0, 1) or the right hand (2, 3). Participants had 4 seconds to enter their overt response after each set of 6 frames in a method we call the multiframe procedure (MFP). Feedback was displayed for 500 ms. The experiment consisted of 5 blocks of 80 trials for a total of 400 trials. Each trial consisted in six visual search frames, yielding 2400 attentional episodes.

Electrophysiological recording

A BioSemi ActiveTwo system (BioSemi Inc., Amsterdam, The Netherlands) was used for the recording of the EEG signal with 64 active Ag/AgCl electrodes mounted on an elastic cap and rereferenced to the algebraic mean of right and left mastoid signals. Electrodes were placed on the participant’s scalp according to the international 10/10 system (Chatrian, 1985; Chatrian, Lettich, & Nelson, 1988). Two electrooculograms were calculated to identify lateral eye movements and blinks through the comparison of pairs of electrodes. The horizontal electrooculogram (HEOG), calculated as the difference between the left and right external canthi electrodes, was used to detect horizontal eye movements. The vertical electrooculogram (VEOG) was calculated as the difference between electrode Fp1 and another electrode placed below the left eye and used to detect blinks.

The EEG was recorded at a sampling rate of 512 Hz, with an antialiasing lowpass filter of 134 Hz was applied during the recordings. An offline bandpass filter 0.05–30 Hz was also applied on the EEG signal. For one participant, that filter was replaced by an offline bandpass filter of 0.05–20 Hz to reduce the signal contamination by alpha activity[2].

Trials with an HEOG difference larger than 25 μV on a 200 ms interval suggested lateral eye movements and were rejected. Trials with a variation of VEOG larger than 50 μV over a 200 ms interval were flagged as blinks and were removed. All trials with artifactual data, identified as a variation of more than 100 μV for any electrode, were also removed.

We averaged HEOG for left-target and right-target trials from 200 to 700 ms post stimuli presentation and used only the data of participants with residual EOG activity less than less than 3.5 mV, 3 mV being slightly too restrictive for two participant in two different conditions. Mean HEOG exceeding 3mV reached that amplitude after 350 ms, and therefore could not affect our N2pc measures, which peaked between 250 and 300 ms (see Figure 3a and 3b). Concerning VEOG, participants with an average difference exceeding 6 μV were also excluded. Overall, no participants were excluded for vertical eye movement and 2 were excluded for horizontal eye movement.

Insert Figure 3a and 3b about here

---

[2] The different filter between one participant and the rest did not introduce any side effect. The more susceptible result to change (the jackknife) showed similar results *F’* (3, 36) = 10.31, $p < .0001$). The Tukey test also showed the same color hierarchy (see page 27). Behavioral performance for this participant was comparable to that of other participants.

Experiment 1 results

Calibration task results

The heterochromatic flicker photometry technique allows the selection of stimuli colors that are all equal in luminance (Walsh, 1953). Despite Walsh's previous results regarding luminance, we measured the luminance for the stimuli of experiment 1, using a Minolta meter, and then tested for significant differences across the 4 luminance means, using a one-way ANOVA. No significant differences were observed (F (3, 36) = 1,31, $p > .28$). This confirmed the expected absence of luminance differences between colors for this particular experiment.

Main experiment

Behavioral results

In our multiple frame procedure (MFP), participants were required to report a target count after each set of six frames. Participants had an average success rate of 90.67 ± 0.07%, with a range of 75% to 99%. No differences were found depending on target orientation (horizontal, n=6, or vertical, n=7, $t(11) = 0.21$, $p > .80$).

ERP results

All subsequent analyses were made on electrodes PO7 and PO8. Time windows are presented in Table 2 and 3.

Multiple Frame Procedure

In order to confirm the stability of attentional deployment across different frame positions in the sequence of frames, we assessed the presence of the N2pc on each MFP frame (1 to 6). The event-related lateralizations (ERLs) for each frame position are shown in Figure 4, amplitudes in Table 1. A repeated measure ANOVA with Frame Position as main factor revealed no significant differences between amplitudes, $F(5, 60) = 1,14$, $p >.35$. In fact, *t*-tests revealed a negativity between 245 and 285 ms significantly different from 0 in all six frames (Frame 1: $t(12) = -3.15$, $p < .01$; Frame 2: $t(12) = -3.76$, $p < .005$; Frame 3: $t(12) = -4.10$, $p < .005$; Frame 4: $t(12) = -3.94$, $p < .005$; Frame 5: $t(12) = -4.35$, $p < .005$; Frame 6: $t(12) = -2.76$, $p < .05$).

Insert Figure 4 about here

Targets and decoys

We assumed that attention would be first deployed to the colored singleton circle, and that subsequently, the orientation of the line in that circle would be evaluated to determine if the display contained a target or a decoy. To know whether or not the electrophysiological activity arising from target and decoys are comparable (and therefore can be averaged for further analyses), components were compared on their amplitude. In order to evaluate this, two time windows were chosen independently for both targets and decoys in order to best fit the individual conditions components (see Figure 5). Paired-sample *t*-tests comparing the target and decoy mean amplitude across their respective Ppc, N2pc, and Ptc (the time range of each component is indicated in Table 2) found no significant differences; Ppc: $t(12) = 1.22$, $p > .24$; N2pc: $t(12) = -1.62$, $p > .13$; Ptc: $t(12) = -1.18$, $p > .25$. The same results were also obtained when a common window was chosen for both the target and decoy conditions of the N2pc and Ppc (Ppc: $t(12) = 1.31$, $p > .21$; N2pc: $t(12) = -2.04$, $p > .06$) confirming that for the purpose of this experiment both conditions were equivalent[3]. For subsequent analyses, these two different types of trials were merged together and are called targets from the point of view of attentional deployment.

Insert Figure 5 about here

Electrophysiology – N2pc

Figure 3a presents grand-averaged event-related lateralizations (ERLs) obtained by subtracting the ispilateral ERP waveform from the contralateral ERP waveform for each singleton color. These averages were time-locked to the onset of the visual search display presentation and included a 200-ms pre-stimulus baseline and extended 700 ms after onset.

Analyses of mean amplitudes were performed on the average voltage in a window starting 20 ms before and extending to 20 ms after the grand average waveform peak for each conditions of the N2pc. The time window boundaries can be found in Table 3 and the mean amplitudes, in Table 4. A repeated measure ANOVA for the Color factor (red, green, blue, or yellow) showed no amplitude main effect, $F(3, 36) = 1.23$, $p > .31$. All N2pc components had an amplitude significantly different from zero (one-sample *t*-tests

---

[3] We intended here to openly expose the verification that both waveforms were actually identical. We chose both a common window and a maximum difference window (to maximize a difference between conditions), in order to demonstrate that even without presuming a common window for the ERP components we still failed to get a significant difference between target and decoys. Since both items reflected the same activity, trials where attentional deployment was to a target or to a decoy were averaged together in subsequent analysis.

versus 0, red: $t\ (12) = -4.10, p < .005$; green: $t\ (12) = -4.48, p < .005$; blue: $t\ (12) = -3.88, p < .005$; yellow: $t\ (12) = -3.69, p < .005$)[4].

We examined the latency of the onset of lateralized activity across color conditions. These analyses used repeated-measures ANOVAs combined with the jackknife method (Kiesel, Miller, Jolicoeur, & Brisson, 2008; Miller, Patterson, & Ulrich, 1998). The use of the repeated measure ANOVA with the jackknife required some corrections to the F value. These corrections compensated for the artificial deflation of the error variance associated with sets of jackknife waveforms ($F' = F / (n\text{-}1)^2$) (Ulrich & Miller, 2001). Latency was estimated as the time at which the waveform first reached amplitude of -0.75 microvolt. The N2pc showed significant latencies differences depending on the color of the singleton, as shown in Figure 3a, $F'\ (3, 36) = 11.57, p < .0001$[5]. Tukey's post-hoc test revealed that conditions in which a potential target was red or blue had an earlier N2pc compared to conditions in which the potential target was green or yellow; while the red and blue N2pc did not differ in latency (R<GY; B<GY;R~B;G~Y). The estimated mean latency for each singleton color can be found in Table 5. Tukey's post-hoc test also required some correction ($H' = H*(n\text{-}1)$) for jackknife measurements (Ulrich & Miller, 2001).

Condition specific voltage maps shown in Figure 6 were produced to examine the scalp distribution of lateralized activity for the N2pc in each color conditions. The

---

[4] That result was explored further because of the apparent amplitude differences visible by eye in Figure 3a. A subsequent paired *t*-test evaluated the presence of a difference between the red-blue average and green-yellow average, but still revealed no significant difference, $t\ (12) = -1.65, p >.12$.

distributions were quite similar, overall, all showing a typical N2pc-like peak near PO7-PO8, as expected from previous research (e.g., Jolicoeur, et al., 2008)

Insert Figure 6 about here

Electrophysiology – Ppc

We also performed analyses on the mean amplitude of the Ppc depending on the color of the singleton for windows shown in Table 3. The waveforms are in Figure 3a and mean amplitudes are in Table 4. These results were submitted to a repeated measure ANOVA with singleton color as a within-subjects factor. The mean amplitudes were different, $F(3, 36) = 6.08$, $p < .005$), and Tukey's post hoc tests showed significant differences with the Ppc for red more positive than for blue or green, and the red-yellow difference missing significance.

The red and yellow Ppc waves were confirmed to be present by *t*-tests against zero, while the two others were not (red: $t(12) = 3.94$, $p < .005$; green: $t(12) = 1.13$, $p > .55$; blue: $t(12) = 1.42$, $p > .15$; yellow: $t(12) = 2.52$, $p < .05$). In Figure 7 we show the voltage distribution map of the Ppc for red and yellow singletons. The distribution is posterior and resembles a polarity-inverted N2pc, although somewhat more inferior and lateral than N2pc. Although the red and yellow Ppcs did not significantly differ at PO7-PO8, our activation maps suggest a more positive red Ppc due to the similar larger amplitude trend found on the surrounding electrodes. That hypothesis was confirmed through a paired sample t-test comparing the red and yellow Ppcs from a pooling of electrodes PO3-PO7 and electrodes PO4-PO8 ($t(12) = 3.87$, $p < .005$).

For the subsequent analyses, we measured the Ppc latency at a threshold set at 50% of the average waveform maximum amplitude between 120 and 200 ms. We found the color factor to be significant (F' (3, 36) = 5.89, p < .005). Tukey's post-hoc tests revealed that the blue Ppc reached its 50% threshold significantly before the green and yellow Ppcs, but not before the red Ppc (B~R; B<GY; R~G~Y; Mean R: 130.1 ms; G: 149.2 ms; B: 112.4 ms; Y: 158.6 ms). In order to verify the presence of a pattern similar to the N2pc, we grouped together the red and blue (RB) as well as the green and yellow (GY) Ppc waves. Comparing these two averaged components, we observed that RB reached its 50% threshold significantly earlier than the GY component (F' (1, 12) = 15,56, p < .005); (Mean RB: 121.2 ms; GY: 153.8 ms).

Insert Figure 7 about here

Electrophysiology – Ptc

The Ptc component can be seen in the waveforms in Figure 3a as a greater positivity contralateral to the color singleton, mainly for red singletons. The mean amplitude of the Ptc for each participant and condition in a window of 20 ms around peak amplitude for the component (see Table 3 for time ranges) were submitted to a repeated measure ANOVA with Color as a within-subjects factor that revealed a significant main effect, $F(3, 36) = 8.64$, $p < .001$. Tukey's post hoc tests showed significant differences between the red and all other colors, the red being more positive (see Table 4 for mean voltages). Although windows of analysis were set to assess the highest visible peak of each color Ptc component, only the red Ptc differed from zero (one-sample *t*-tests versus 0, red: ($t(12) = 3.94$, $p < .005$; green: $t(12) = -0.42$, $p > .65$; blue: $t(12) = 0.57$, $p > .55$; yellow: $t(12) = -0.13$, $p > .85$). A voltage distribution map of the red Ptc can be seen in

Figure 8. The voltage distribution map of the Ptc is similar to the Ppc in position and polarity.

Insert Figure 8 about here

Discussion- Experiment 1

Through ERPs we evaluated how different colors influenced lateralized event-related potentials (ERLs) that reflect preattentional and attentional processes, particularly attentional deployment. We designed a visual search task in which a single colored item, a singleton target or decoy was shown in red, green, blue, or yellow among grey items (distractors). Singletons and grey distractors all had the same luminance (which was equated psychophysically for each participant). The experimental design left only attention and color-specific differences as probable causes of the observed effects.

There were two main findings in experiment 1. Firstly, we observed that red or blue singletons triggered an earlier N2pc compared to green or yellow singletons (red ~ blue < green ~ yellow). Secondly, significantly higher amplitudes for the red Ppc and Ptc suggest a stronger attentional signal by the red target singleton.

Our first results regarding the N2pc latency confirms and extends earlier findings (Fortier-Gauthier, Dell'acqua, & Jolicoeur, 2013), in showing that the N2pc has an earlier onset latency for red than for green singletons, which we here extended here to show a significantly earlier response to blue than to yellow. The color attentional hierarchy we obtained differs from previous behavioral results (Lindsey, et al., 2010; Tchernikov & Fallah, 2010). Even considering the small differences in methodology, the shorter N2pc latency for a blue target singleton differs from previous results. Interestingly, the grouped Ppc waves show the same color hierarchy showed with the N2pc. These results were not as robust as for the N2pc results probably because of the smaller amplitude of the Ppc component. However, from these results, we can postulate a mechanism differentially sensitive to variations in stimulus color that responds prior to the onset of the N2pc.

A few hypotheses could explain our color hierarchy. First, it could be that some colors may be easier to discriminate from grey. That possibility is evaluated later in Experiment 2a and 2b. Second, regarding solely the results to blue targets, we could hypothesize that a non equiluminant blue target could explain its shorter latency. Previous results showed that the bleaching of S-cones (or “blue” cones) does not affect in a large way results of tasks such as the heterochromatic flicker photometry results (Cavanagh, MacLeod, & Anstis, 1987). Knowing this, one could propose that our calibration task, a modified version of the heterochromatic flicker photometry, did not yield equiluminant colors. That proposal can be discounted for two reasons. Firstly, resulting luminance values, after adjustment, were measured with an instrument and the measured values were submitted to statistical analysis. The observed luminances were not statistically different across colors. Secondly, the results of Cavanagh and his collaborators (1987) showed that the contribution of blue cone activity to the luminance channel is considerably weaker than for the two other cone populations. This reduces the likelihood that luminance differences across blue singletons and green or yellow singletons was the main cause of the attentional differences across colors, particularly given that the luminances differences were small, at best (given the results of the flicker photometry and physical photometry).

Another hypothesis for our color hierarchy could be derived based on earlier result on linear separability between colors in color space (Bauer, Jolicoeur, & Cowan, 1996). In the present experiment, only two dimensions in color space need to be considered because all colors were equiluminant (luminance being one of the three dimensions). Furthermore, throughout the experiment, only one color was shown at a time, so the creation of a single linear separation per trial was sufficient to perform the task[6]. Considering the experimental results presented, it could be surmised that the creation/activation of a two dimensional linear separation is faster for the colors that trigger faster attentional deployment (red and blue) than for the other colors (green and yellow). That possibility is further investigated in Experiment 2a and 2b.

A third hypothesis for our color hierarchy would be that red is furthest, and blue farther from grey, in an appropriate color space, than yellow or green. This would mean that yellow or green would be less discriminable from grey than red or blue (Bauer, et al., 1996, see page 1453 & 1464). Previous research showed that, as the distance between target and distractors expands in a color space, the cost in RTs of adding more distractors in a visual search task becomes increasingly small. Figure 9 shows a 2 dimensional representation of the mean of the colors obtained from the calibration task in the CIE L*ab color space (the figure is two dimensional because of equiluminance). This color space was designed so as to optimize the relationship between distance in the space and differences in discriminability among nearby colors. That figure shows differences in the distance of the different colors and grey, which might provide a basis to explain our results. For example, the advantage for red over other colors could be explained because red is further from grey than the other colors. One problem for this account, however, is that blue was not further from grey than green or yellow. Moreover, the threshold for the

---

[6] For that reason, the creation of a linear separation is always possible, as the creation of a line separating only two different points in space was always possible

perception of different colors in the CIE L*ab space is very low (i.e., is reached at a short distance, see A. L. Nagy, R. R. Sanchez, & T. C. Hughes, 1990; Olds, Cowan, & Jolicoeur, 1999). Considering the actual colors position in color space (see Figure 9) a distance factor to the grey color of this magnitude is an unlikely candidate to explain differences of N2pc latency between colors because a ceiling effect for the discrimination of the colors is most likely in place for much closer (to grey) colors than our particular yellow or green (further explored in Experiments 2a and 2b).

Insert Figure 9 about here

Our second main result suggests increased salience for red targets, as red target trials showed higher Ppc and Ptc amplitude. Concerning the Ppc results, it has been verified that the red target had higher amplitude than the green and blue targets. This suggests that the imbalance in the visual display caused by the red target had larger attentional repercussions than for blue or green target colors. We suppose this higher Ppc could reflect higher attentional selectivity for red, which could in turn result in shorter RTs in visual search involving red vs other colored stimuli (Lindsey, et al., 2010; Tchernikov & Fallah, 2010). The absence of amplitude effect between the red and yellow Ppc is somewhat puzzling and does not reflect the effects observed on the N2pc or the Ptc (and is likely due to noise associated with the measurement of a component with a relatively small amplitude).

Studies interested in exploring the Ptc have not considered color as a possible factor up until now (Hilimire, et al., 2009, 2010, 2011). Although color saturation was a factor in a previous study, different colors were not compared (Hilimire, et al., 2010). Hillimire et al. suggest that a more positive Ptc component reflects higher distractor inhibition in order to isolate a target. That would imply that the distractors surrounding red targets needed more inhibition after initial deployment in order for the task to be completed successfully, which is unlikely since the distractors are identical between color condition and that red was the most easily separable color used (based on distance from grey, Figure 9). This would in turn suggest that the red triggers both a faster attentional deployment, but also enhances the distractor inhibition process. It is not clear that this is the most coherent interpretation of the results, however.

Interestingly, these results also contribute to confirm that the Ppc and Ptc reflect the ERP representation of an unbalanced visual display but that these mechanisms do not simply reflect an imbalance in luminance.

Experiment 2a and 2b

Experiment 2a and b were behavioural control experiments designed to determine whether the discriminability of stimuli from grey could account for the results of experiment 1. In these two experiments, two items were shown simultaneously in a same/different task, in which participants had to indicate whether two coloured disks were the same color or not. We expected to find no difference in RTs to different colors in the *same/different* task. Such results would allow us to reject the possibility that some colors may be easier to discriminate from grey. Experiment 2a and 2b solely differed in the stimulus design (see below).

Method

Participants

Participant for Experiment 2a (8 males and 16 females) had a mean age of 22.21 years (S.E. = 2.6, range 19–27), and participants experiment 2b (12 males and 14 females) had a mean age of 22.96 years (S.E. = 2.6, range 22–28) for a total of 50 control participants.

Control tasks

Stimuli

The visual display of both tasks differed from the ERP task (see Figure 10ab (first task, with circles) and 10cd (second task, with disks)). In both control tasks, only two stimuli instead of ten were displayed. Visual properties of the circles/disks (size, distance from fixation) were the same as disks from the ERP task. The only difference between the first and second control tasks was the use of disks in the first and circles in the second. For both tasks, each stimulus could be of five possible colors: grey or one of the four colors obtained through our calibration task.

Insert Figure 10 about here

Two visual conditions could be shown. For the *same* condition, stimuli could either be both grey or both coloured (Figure 10a and 10c). For the *different* condition, one stimulus would be grey while the other was coloured (Figure 10b and 10d). Two different coloured stimuli were not shown simultaneously, as a similar condition was not present in Experiment 1. Although two conditions were needed for the task, the condition of greatest interest for the purpose of our inquiry was the *different* condition, which evaluated color discriminability from grey distractors, which was also required from participants in Experiment 1.

Procedure

First, a 500 ms fixation cross was shown. Then, two stimuli were displayed above and under the cross for 200 ms. After that display, participants were instructed to simply press “v” if both stimuli were the same color and “b” if colors differed. The experiment consisted in 455 trials of which 70 compared a grey stimulus to a *different* color, for a total of 280 color-to-grey pairings.

Experience 2a and 2b results

Behavioural results

The average error rate for experiment 2a was 3.5% (s.d. = 2.4) while average error rate for experiment 2b was 4.3% (s.d. = 3.4). Outliers, defined as trials with RTs two and a half standard error longer or shorter than the mean, were rejected from all analyses. Experiment 2a had 3.5% outliers and experiment 2b 3.3%. From the initial 455 trials, an average of 93.1% (s.d. = 2.5) were kept for experiment 2a and an average of 92.5% (s.d. = 3.4) were kept for experiment 2b once errors and outliers were removed.

For each control experiment a repeated measure ANOVA evaluated the RTs using a 2 levels factor Type (conditions *same* vs. *different)* by 4 levels factor Color (red, green, blue, or yellow) design.

Experiment 2a – Circles

Mean RTs for each condition can be found in Table 6. Analyses did not reveal any interaction, *F*(3, 75) = 1.97, *p* > .15, nor any main effect, Type: *F*(1, 25) = 0.45, *p* > .51; Color: *F*(3, 75) = 1.90, *p* > .16.

Experiment 2b– Disks

We found the Type (*same* or *different*) factor main effect to be marginally significant, *F*(1, 25) = 3.40, *p* < .07, and the Color factor main effect to be significant, *F*(3, 75) = 5.42, *p* < .01, but no significant interaction effect was present, *F*(3, 75) = 1.40, *p* > .25. We performed additional repeated measure ANOVAs for the color factor separately for each Type (*same* and the *different* conditions) in order to establish if the Color main effect was present across both conditions. These analyses did not show any significant differences between colors, *F*(3, 75) = 2.10, *p* > .13, for the *different* condition. No significant results were also obtained with one-tailed paired sample *t*-test comparing together a group formed of the averaged red and blue RTs and the averaged green and yellow RTs for the *different* condition, *t*(25) = 1.43, p > .16, which were the color grouping that were observed in our ERP Experiment (see Figure 5 for the ERL waveforms). However, a significant effect of color for the *same* condition, *F*(3, 75) = 5.96, *p* < .01, was found. Tukey's post-hoc tests revealed significantly shorter RTs for the red disks compared to blue and yellow disks (see Table 6 for mean RTs by condition).

Discussion Experiment 2a and 2b

Experiment 2 acted as a control task, evaluating participant's capacity to discriminate two coloured circle (experiment 2a) or disk (experiment 2b) as *same* or *different*. *Same* condition consisted in two items of the same color (either red, green, blue, yellow or grey) shown simultaneously and *different* condition consisted in a grey item and a differently coloured item, also shown simultaneously. Our results confirm that all colors have the same discriminability from grey, since no significant differences were found for the *different* condition which reproduced, especially the circle experiment (2a), the color contrast present in our experimental task. Furthermore, the equivalent mean RT between colors in the *different* condition do not support the hypothesis that a different discriminability explains the N2pc latency effect in our experimental task. The control experiments did not reveal any RT pattern that would lead us to believe the red and blue colors had a higher discriminability than other colors during the Experiment 1.

The *same* condition was added to our control tasks in order to have a multiple choice task. The main objective of the control tasks was therefore to evaluate the eventual RT effect that could be present in the *different* condition. The color main effect in the *same* condition is hard to explain and requires further investigations.

In the following lines, we will emphasize the absence of a colour effect in the 'different' condition because finding a difference seems closer to what was required in the ERP search task than deciding that two colours were the same. In order to locate potential targets in the ERP experiment, a colour difference had to be detected and used to guide attention.

As mentioned earlier in experiment 1, it could be surmised that the creation/activation of a two dimensional linear separation is faster for the colors that trigger faster attentional deployment (red and blue) than for the other colors (green and yellow). We reject that possibility on the basis of the results of both control tasks. If separation was easier for a color, we would obtain faster RTs for that color in one of the control task for the *different* condition. Given that no significant RT differences were observed in the *different* condition, the hypothesis of faster separations — or any discriminative filter activation/creation — for some colors versus others needs to be ruled out. These results are also very informative when considered together with the Ppc results from experiment 1. Indeed, experiment 2 shows that that the Ppc amplitude effect could not be caused by properties that would automatically lead to shorter reaction times (i.e. luminance or discriminability), as this would have been reflected in RT differences for the *different* conditions.

General discussion

Generally, red targets tended to produce a larger Ppc, an earlier N2pc, and a larger Ptc --- all lateralized ERP components relative to a lateral stimulus --- relative to targets in other colors. Blue targets also produced an earlier N2pc relative to yellow and green. We equated luminance using a modified version of the heterochromatic flicker photometry to minimize possible luminance differences between colors. Although the electrophysiological results appear to be robust, our attempts to relate them to a simple discriminability account were somewhat inconclusive. Previous research that found color hierarchy used evolutionist theories (i.e., quickly deploying attention to lips (a desaturated red) would allow better communication and possibly better survival); or cone proportion in the retina (long wavelength/red cones > middle wavelength/green cones > short wavelength/blue cones) to explain the importance of the red (Lindsey, et al., 2010; Tchernikov & Fallah, 2010). The present results, without refuting past observations, cannot use similar hypotheses because of the presence of the early blue N2pc. This likely reflects either a non-controlled variable or some gap in the sparse research dedicated to color-specific differences in attention. Despite this, the present conclusions should make ERP researchers aware that equiluminance is not sufficient for eliminating all color related-bias in a visual search display. Similarly, equating distance in a color space like the CIE L*ab space may also not provide a complete solution.

Some of the present results may be related to the koniocellular pathway. Although first described in the late 40's, this pathway has been neglected for a long time in terms of its contribution to visual perception. More recent data shows that the koniocellular pathway links S-cones, and consequently mostly blue-on responses, to multiple visual areas, including the color selective blobs in the primary visual cortex of monkeys (Hendry & Reid, 2000; Komatsu, 1998). These results challenge the notion that color information is essentially carried by the parvocellular pathway, which contains only a small proportion of input from S-cones (Chatterjee & Callaway, 2002; Martin, White, Goodchild, Wilder, & Sefton, 1997). In that way, our results could be explainable by an early integration of the blue-on responses in visual areas. As to why this effect would only show on ERPs and not in behavioral data remains unclear. Despite this uncertainty, other results have shown a rapid integration of magnocellular and koniocellular information in motion perception, which could suggest such an early integration also occurs in attentional selection based on color cues (Morand et al., 2000).

Some apparent discrepancies exist between results from our Experiment 1 and 2. In our ERP task, we observed a N2pc delay between different colors, but in Experiment 2, we observe no corresponding RT difference in the *different* color conditions. Because the results from experiment 2 do not support the hypothesis of differences in discrimination between colors, another factor needs to be put forward to explain the different pattern of results between the two experiments. The two tasks used colored circles obtained through the same calibration procedure and displayed at the same eccentricity from a fixation cross, so these factors cannot be used to explain the dissimilarities. What differs between tasks are 1) the number of items; 2) the nature of the task; 3) the distance between each item; and 4) the specific position of the items in the visual displays. About the number of items, one could be concerned by the transition of strategy or differences in difficulty between tasks. In the present case, because the colors were very different, a significant difficulty difference due to the number of items between both tasks is unlikely because all colors were easily distinguishable from the grey items (Bauer, et al., 1996). For the same reason, a change in strategy is unlikely to be related to the number of items present since in both tasks, colored items likely popped-out from the grey items, likely reducing disruptive effects of the grey items (A. L. Nagy, et al., 1990; Olds, et al., 1999; Treisman & Gelade, 1980). Regarding the difference in the nature of the task, Experiment 2a and b, implying simple color discrimination, was generally easier than Experiment 1, which required both a color discrimination and the identification of line orientation within the selected item. This difference in task difficulty may have resulted in less effort exerted in Experiment 2a and 2b, which may have attenuated possible discriminability effects across colors. The distance between each target and non-salient items would tend to make the task RTs slower for closer distractors (Mazza, et al., 2009b). In their study, Mazza et al. (2009b) did not match this RT effect with neither an amplitude nor a latency effect on the

N2pc. This would tend to disqualify this factor as a possible explanation of our discrepancies. The effect would also need to be color selective, which was not reported in previous research. Finally, the fact that control items were presented on the vertical midline instead of lateral in each hemifield was another difference between the presentation conditions in Experiment 1 and the control conditions in Experiment 2. Although there are many electrophysiological and behavioural effects related to visual fields (upper vs. lower, left vs. right), it is not clear in the present case that such differences would enhance possible color discriminability effects in left-right lateral presentations (Experiment 1) or reduce them in upper-lower presentations (Experiment 2), although this remains possible.

Although the results from the ‘different’ conditions of Experiment 2a and 2b did not reveal a greater ability to discriminate red from grey than for other colors, results from the ‘same’ conditions produced shorter RTs to respond that two colored stimuli where the same when they were red than for other colors (Table 6). This pattern, particularly evident in Experiment 2b, could reflect the same advantage of red over other colors as observed in Experiment 1 if attention is more quickly deployed to a red target. This advantage would be present for both red stimuli in the same condition than for other colors, even if subsequent operations (such as color comparison or response selection) unfolded at the same rate for all colors). Although red seemed special in some of the results of Experiment 2, we found no equivalent evidence for blue. Overall, the results converge in suggesting that red has a special status in guiding attention in a variety of situations that require attentional deployment to visual stimuli.

Conclusion

The color effects observed on the N2pc, Ppc, and Ptc, along with results obtained from Experiment 2a and 2b, suggest careful evaluation of chromatic factors in subsequent studies making use of colored stimuli. Equiluminant colors do not have an equivalent effect on attentional mechanisms, as reflected by amplitude and latency effects observed across different target colors in the present study. Stimuli in red appear to attract attention more efficiently than stimuli in other colors (particularly green or yellow), even under pop-out conditions. The present results reinforce earlier finding and suggest that the red advantage deserves further study.

References

Ansorge, U., et al. (2013). Contingent capture in cueing: the role of color search templates and cue-target color relations. *Psychol. Res.*, 1-13. doi:10.1007/s00426-013-0497-5

Bacon, W. F., et al. (1994). Overriding stimulus-driven attentional capture. *Percept & Psychophys, 55*(5), 485-496.

Bauer, B., et al. (1996). Visual search for colour targets that are or are not linearly separable from distractors. *Vision Res., 36*(10), 1439-1466. doi:10.1016/0042-6989(95)00207-3

Bone, R. A., et al. (2004). Heterochromatic flicker photometry. *Arch. Biochem. Biophys., 430*(2), 137-142. doi:DOI: 10.1016/j.abb.2004.04.003

Brisson, B., et al. (2007). The N2pc component and stimulus duration. *Neuroreport, 18*(11), 1163-1166. doi:http://dx.doi.org/10.1097/WNR.0b013e3281e72d1b

Brisson, B., et al. (2007). Stimulus intensity affects the latency but not the amplitude of the N2pc. *Neuroreport, 18*(15), 1627-1630. doi:http://dx.doi.org/10.1097/WNR.0b013e3282f0b559

Carter, R. C. (1982). Visual search with color. *J. Exp. Psychol. Hum. Percept. Perform., 8*(1), 127-136. doi:http://dx.doi.org/10.1037/0096-1523.8.1.127

Cavanagh, P., et al. (1987). Equiluminance: Spatial and temporal factors and the contribution of blue-sensitive cones. *Journal of the Optical Society of America, A, Optics, Image & Science, 4*(8), 1428-1438. doi:http://dx.doi.org/10.1364/JOSAA.4.001428

Chatrian, G. E. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activity. *Am J Electroencephalogr Technol, 25*, 83-92.

Chatrian, G. E., et al. (1988). Modified nomenclature for the "10%" electrode system. *J Clin Neurophysiol, 5*(2), 183-186.

Chatterjee, S., et al. (2002). S cone contributions to the magnocellular visual pathway in macaque monkey. *Neuron, 35*(6), 1135-1146. doi:S0896627302008747 [pii]

Clark, S. E. (1969). Retrieval of color information from preperceptual memory. *J. Exp. Psychol., 82*(2), 263-266. doi:http://dx.doi.org/10.1037/h0028135

Corriveau, I., et al. (2012). Electrophysiological evidence of multitasking impairment of attentional deployment reflects target-specific processing, not distractor inhibition. *Int. J. Psychophysiol.*(0). doi:10.1016/j.ijpsycho.2012.06.005

Cowan, N. (2000). The magical number 4 in short-term memory: A reconsideration of mental storage capacity [Comment/Reply]. *Behav. Brain Sci., 24*(1), 87-185. doi:http://dx.doi.org/10.1017/S0140525X01003922

Dell'Acqua, R., et al. (2012). Sparing from the attentional blink is not spared from structural limitations. *Psychon B Rev, 19*(2), 232-238. doi:10.3758/s13423-011-0209-3

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalogr. Clin. Neurophysiol., 99*(3), 225-234. doi:http://dx.doi.org/10.1016/0013-4694%2896%2995711-9

Fortier-Gauthier, U., et al. (2013). The "red-alert" effect in visual search: Evidence from human electrophysiology. *Psychophysiology, 50*(7), 671-679. doi:10.1111/psyp.12050 [doi]

Hendry, S. H. C., et al. (2000). The koniocellular pathway in primate vision [Review]. *Annu. Rev. Neurosci., 23*, 127-153. doi:10.1146/annurev.neuro.23.1.127

Hickey, C., et al. (2009). Electrophysiological indices of target and distractor processing in visual search. *J. Cogn. Neurosci., 21*(4), 760-775. doi:http://dx.doi.org/10.1162/jocn.2009.21039

Hilimire, M. R., et al. (2009). Competitive interaction degrades target selection: An ERP study. *Psychophysiology, 46*(5), 1080-1089. doi:10.1111/j.1469-8986.2009.00846.x

Hilimire, M. R., et al. (2010). Event-Related Potentials Dissociate Effects of Salience and Space in Biased Competition for Visual Representation. *PLoS ONE, 5*(9), e12677. doi:10.1371/journal.pone.0012677

Hilimire, M. R., et al. (2011). Dynamics of target and distractor processing in visual search: Evidence from event-related brain potentials. *Neurosci. Lett., 495*(3), 196-200. doi:10.1016/j.neulet.2011.03.064

Jolicoeur, P., et al. (2008). Dissociation of the N2pc and sustained posterior contralateral negativity in a choice response task. *Brain Res., 1215*(0), 160-172. doi:10.1016/j.brainres.2008.03.059

Kiesel, A., et al. (2008). Measurement of ERP latency differences: A comparison of single-participant and jackknife-based scoring methods. *Psychophysiology, 45*(2), 250-274. doi:http://dx.doi.org/10.1111/j.1469-8986.2007.00618.x

Komatsu, H. (1998). Mechanisms of central color vision. *Curr. Opin. Neurobiol., 8*(4), 503-508. doi:10.1016/s0959-4388(98)80038-x

Lennert, T., et al. (2011). Attentional Modulation of Neuromagnetic Evoked Responses in Early Human Visual Cortex and Parietal Lobe following a Rank-Order Rule. *J. Neurosci., 31*(48), 17622-17636. doi:10.1523/jneurosci.4781-11.2011

Lindsey, D. T., et al. (2010). Color Channels, Not Color Appearance or Color Categories, Guide Visual Search for Desaturated Color Targets. *Psychol. Sci., 21*(9), 1208-1214. doi:10.1177/0956797610379861

Liu, Q., et al. (2009). The N2pc component in ERP and the lateralization effect of language on color perception. *Neurosci. Lett., 454*(1), 58-61. doi:10.1016/j.neulet.2009.02.045

Luck, S. J., et al. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *J. Exp. Psychol. Hum. Percept. Perform., 20*(5), 1000-1014. doi:http://dx.doi.org/10.1037/0096-1523.20.5.1000

Martin, P. R., et al. (1997). Evidence that Blue-on Cells are Part of the Third Geniculocortical Pathway in Primates. *Eur. J. Neurosci., 9*(7), 1536-1541. doi:10.1111/j.1460-9568.1997.tb01509.x

Mazza, V., et al. (2009a). An electrophysiological assessment of distractor suppression in visual search tasks. *Psychophysiology, 46*(4), 771-775. doi:http://dx.doi.org/10.1111/j.1469-8986.2009.00814.x

Mazza, V., et al. (2009b). Attention selection, distractor suppression and N2pc. *Cortex, 45*(7), 879-890. doi:http://dx.doi.org/10.1016/j.cortex.2008.10.009

Miller, J., et al. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology, 35*(01), 99-115. doi:doi:null

Morand, S., et al. (2000). Electrophysiological evidence for fast visual processing through the human koniocellular pathway when stimuli move. *Cereb. Cortex, 10*(8), 817-825. doi:http://dx.doi.org/10.1093/cercor/10.8.817

Nagy, A. L., et al. (1990). Visual search for color differences with foveal and peripheral vision. *J. Opt. Soc. Am. A, 7*(10), 1995-2001.

Olds, E., et al. (1999). Stimulus-determined discrimination mechanisms for color search. *Attention, Perception, & Psychophysics, 61*(6), 1038-1045. doi:10.3758/bf03207611

Posner, M. I. (1980). Orienting of attention. *Q. J. Exp. Psychol., 32*(1), 3-25. doi:http://dx.doi.org/10.1080/00335558008248231

Regier, T., et al. (2009). Language, thought, and color: Whorf was half right. *Tics, 13*(10), 439-446. doi:http://dx.doi.org/10.1016/j.tics.2009.07.001

Robitaille, N., et al. (2006). Effect of cue-target interval on the N2pc. *NeuroReport: For Rapid Communication of Neuroscience Research, 17*(15), 1655-1658. doi:http://dx.doi.org/10.1097/01.wnr.0000236859.16457.34

Sperling, G. (1960). The information available in brief visual presentation. *Psychol. Monogr., 74*(11, Whole No. 498), 29.

Tchernikov, I., et al. (2010). A Color Hierarchy for Automatic Target Selection. *PLoS ONE, 5*(2), e9338. doi:10.1371/journal.pone.0009338

Treisman, A. M., et al. (1980). A feature-integration theory of attention. *Cogn. Psychol., 12*(1), 97-136. doi:http://dx.doi.org/10.1016/0010-0285%2880%2990005-5

Ulrich, R., et al. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology, 38*(05), 816-827. doi:http://dx.doi.org/10.1017/S0048577201000610

Von Wright, J. M. (1972). On the problem of selection in iconic memory. *Scand. J. Psychol., 13*(1), 159-171. doi:10.1111/j.1467-9450.1972.tb00064.x

Walsh, J. W. T. (1953). *Photometry*. London: Constable and Company Limited.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychon B Rev, 1*(2), 202-238.

Woodman, G. F., et al. (2003). Serial deployment of attention during visual search. *J. Exp. Psychol. Hum. Percept. Perform., 29*(1), 121-138. doi:http://dx.doi.org/10.1037/0096-1523.29.1.121

Zhao, G., et al. (2011). The amplitude of N2pc reflects the physical disparity between target item and distracters. *Neurosci. Lett., 491*(1), 68-72. doi:10.1016/j.neulet.2010.12.066

Table 1. Mean amplitude and standard deviation of the N2pc in microvolt (μV) for each frame position.

	N2pc (s.d.)
Frame 1	-.98 (1.12)
Frame 2	-1.21 (1.16)
Frame 3	-1.21 (1.07)
Frame 4	-1.21 (1.10)
Frame 5	-1.23 (1.02)
Frame 6	-.81 (1.05)

Table 2. Time windows for targets and potential targets (color singleton containing a non-target line orientation) for the N2pc, Ppc, and Ptc components, in milliseconds, post stimulus.

	N2pc	Ppc	Ptc
Potential target	240–280	130–170	335–375
Real target	235–275	145–185	335–375

Table 3. Time windows for N2pc, Ppc, and Ptc in milliseconds, post stimulus, for each singleton color.

	N2pc	Ppc	Ptc
Red	215–255	130–170	330–370
Green	260–300	160–200	340–380
Blue	240–280	130–170	335–375
Yellow	260–300	160–200	340–380

Table 4. Mean amplitude (μV) and standard deviation for the N2pc, Ppc, and Ptc, for each singleton color.

	N2pc	Ppc	Ptc
Red	-1.50 (1.32)	0.88 (.80)	0.98 (.89)
Green	-1.17 (.94)	0.16 (.52)	-0.10 (.85)
Blue	-1.60 (1.49)	0.24 (.63)	0.18 (1.14)
Yellow	-1.13 (1.10)	0.49 (.71)	-0.04 (1.15)

Table 5. Mean latency of the onset of the N2pc, in milliseconds (ms), and standard deviation, for each singleton color.

	N2pc (s.d.)
Red	205 (3.15)
Green	250 (2.48)
Blue	223 (2.76)
Yellow	253 (4.06)

Table 6. Mean response time (ms) and standard deviation for each control tasks, from Experiment 2.

	Exp. 2a - same	Exp. 2b - same	Exp. 2a - different	Exp. 2b - different
Red	446 (94.6)	477 (135.8)	459 (142.3)	529 (207.2)
Green	498 (189.1)	487 (133.9)	469 (150.4)	524 (172.6)
Blue	473 (118.0)	520 (160.7)	493 (186.8)	561 (213.1)
Yellow	516 (228.7)	515 (159.2)	466 (146.9)	526 (188.9)

Figure Captions

Figure 1 : Illustration of the ERP task, the Multiframe Presentation. The arrow represents the passage of time. The first visual frame, not visible here, displayed a fixation cross for 500 ms. Illustrated is a trial with vertical as a target orientation. Six frames were presented for 200 ms with an inter-stimulus interval of 600±100 ms.. At the end of each presentation, participants had to indicate whether 0, 1, 2 or 3 targets were presented within the MFP.

Figure 2: Illustration of the calibration task. Two altering frames containing ten numbered circles were presented at a 15 Hertz frequency. Each circle of the colored frame (frame A) displayed a slightly different luminance value, while the grey circle frame (frame B) had constant luminance value in each frame. Participants had to choose which circle showed the least flickering through a numeric keypad. Colored frames could display red, green, blue or yellow circles, depending on the color being calibrated.

Figure 3a : Grand average of event-related lateralization waveforms (contralateral minus ipsilateral) at PO7/PO8 time-locked to the onset of the coloured item presentation. Red refers to the presentation of a red lateralized item, and so forth for green, blue and yellow. Tick marks on the time axis represent 100 ms increments.

Figure 3b: Grand average of HEOG: target to the right: doted, target to the left: continuous, for each color, calculated as the difference between the left and right external canthi electrodes. Negative deflection reflects eye movement towards target.

Figure 4: Grand average of event-related lateralization waveforms (contralateral minus ipsilateral) at PO7/PO8 time-locked to the onset of the coloured item presentation in each frame. Tick marks on the time axis represent 100 ms increments.

Figure 5 : Grand average of event-related lateralization waveforms (contralateral minus ipsilateral) at PO7/PO8 time-locked to the onset of the coloured item (dotted lines refer to lateralized targets, continuous lines refer to lateralized decoys). Tick marks on the time axis represent 100 ms increments

Figure 6 : Grand average scalp voltage distributions of the N2pc for each color.

Figure 7 : Grand average scalp voltage distributions of the Ppc for each color.

Figure 8: Grand average scalp voltage distributions of the Ptc for each color.

Figure 9: Illustration of the mean results of the calibration task for the ERP task. The colors are represented in the CIE L*ab color space. The x axis corresponds to the a value and the y axis to the b value. The L value, referring to luminance is not illustrated since all colors are equiluminant.

Figure 10: Illustration of the Experiment 2a and 2b. Not shown here, a fixation cross that preceded every trial for 500 ms. After the fixation cross, participants were shown either a frame of the same (exp 2a: frame a or c) or different (exp 2b: frame b or d) condition. Disks and circles stimuli are from in a different task.

Figure 1

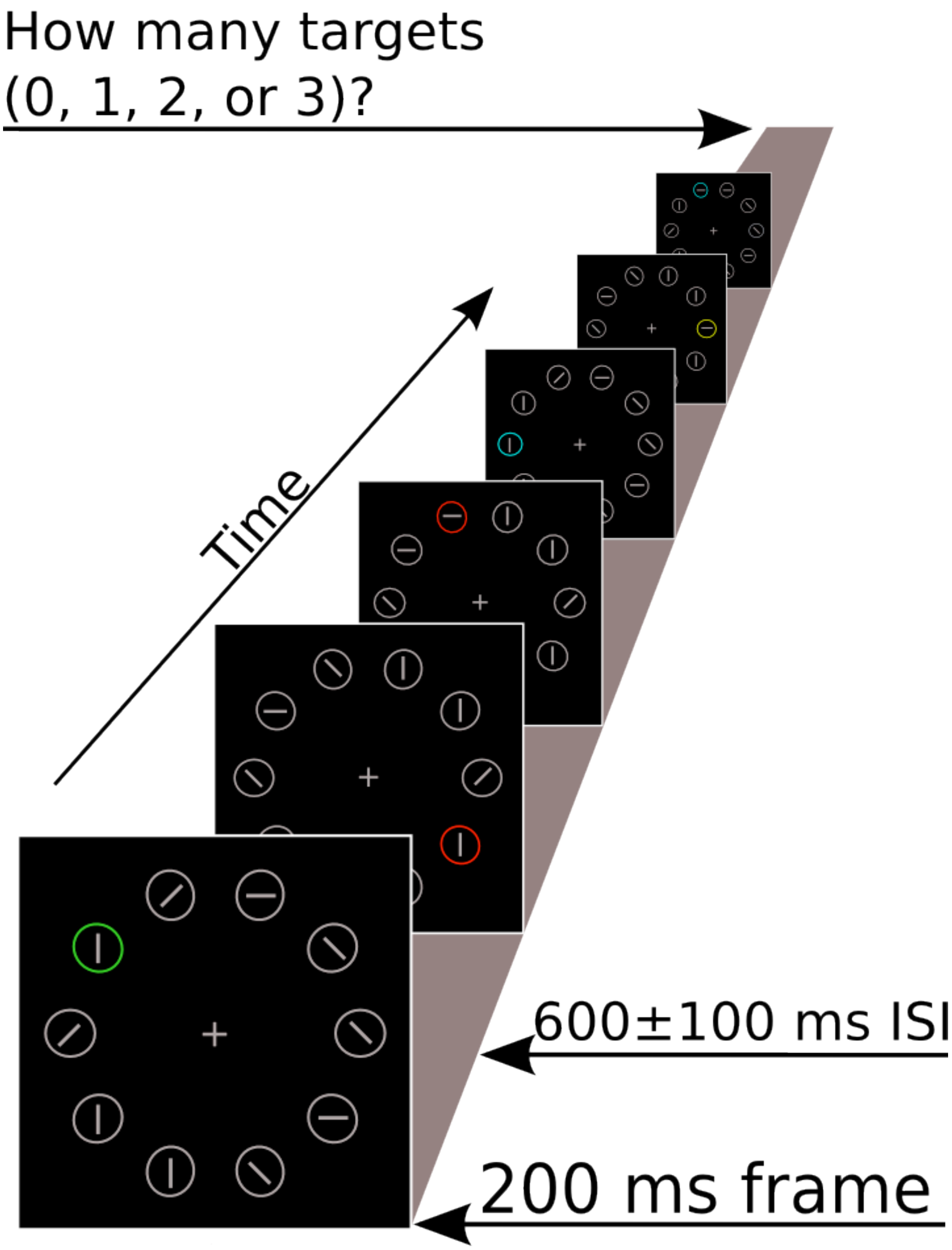


Figure 2

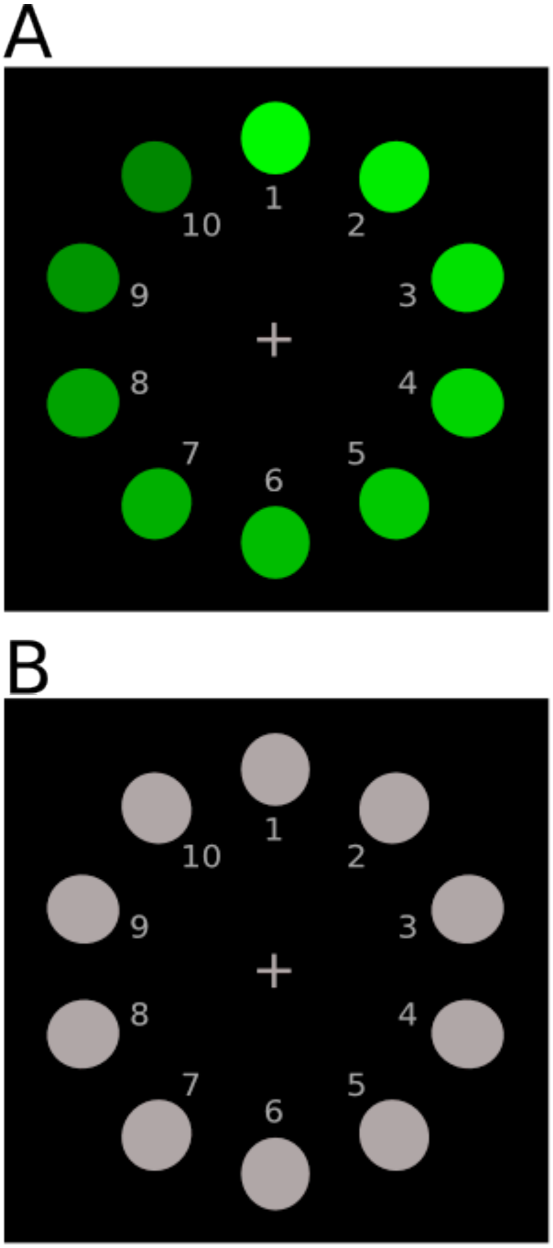


Figure 3a

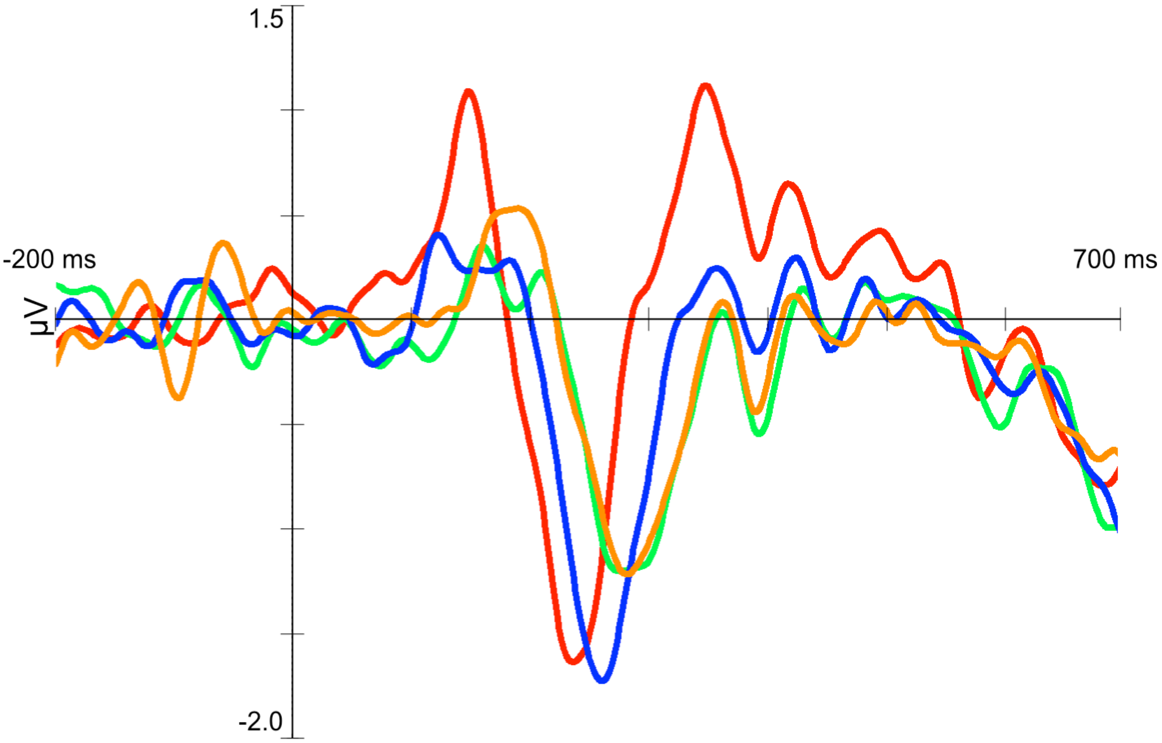


Figure 3b

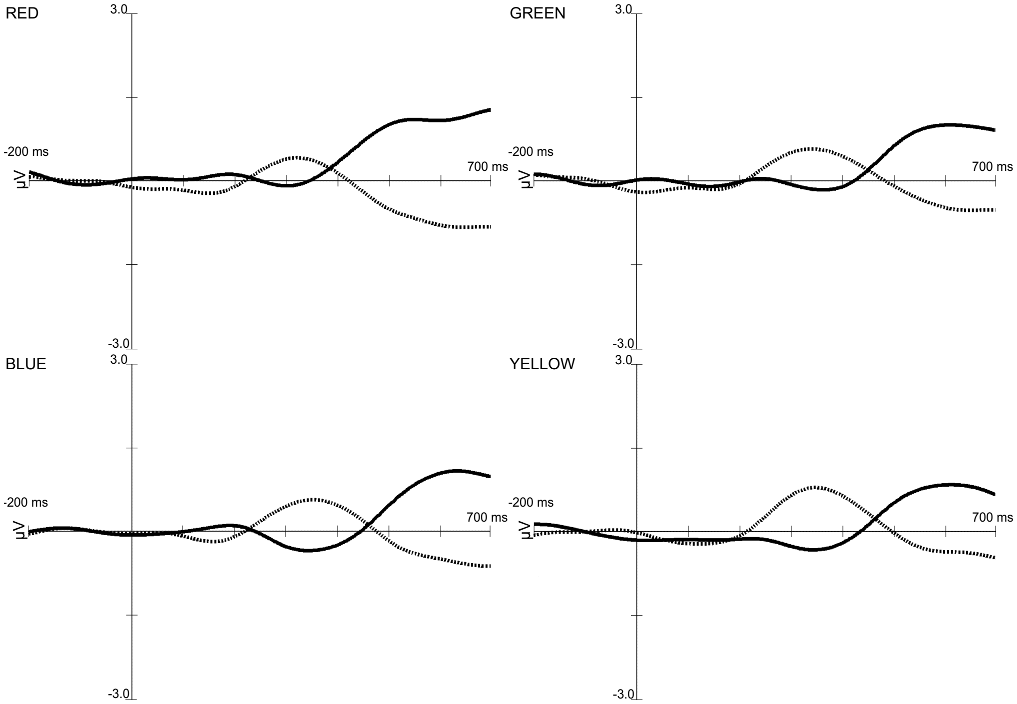


Figure 4

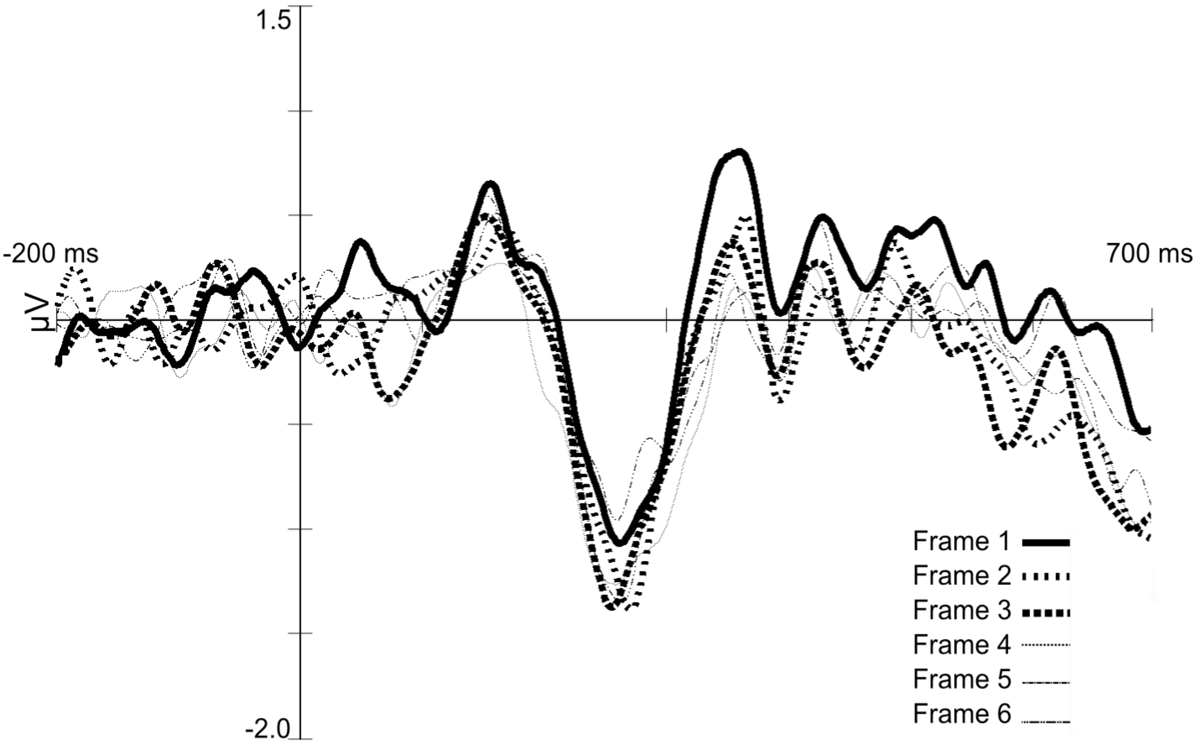

1.5
-200 ms
700 ms
µV
-2.0
Frame 1
Frame 2
Frame 3
Frame 4
Frame 5
Frame 6

Figure 5

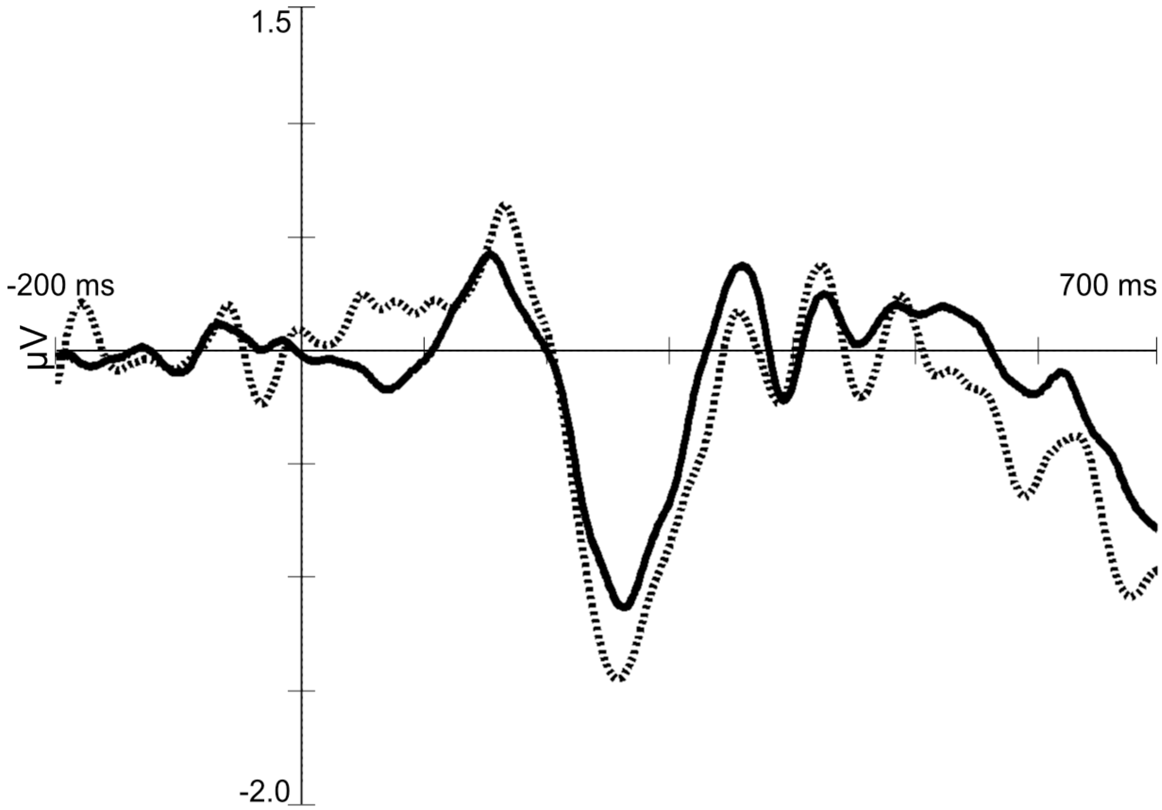


Figure 6

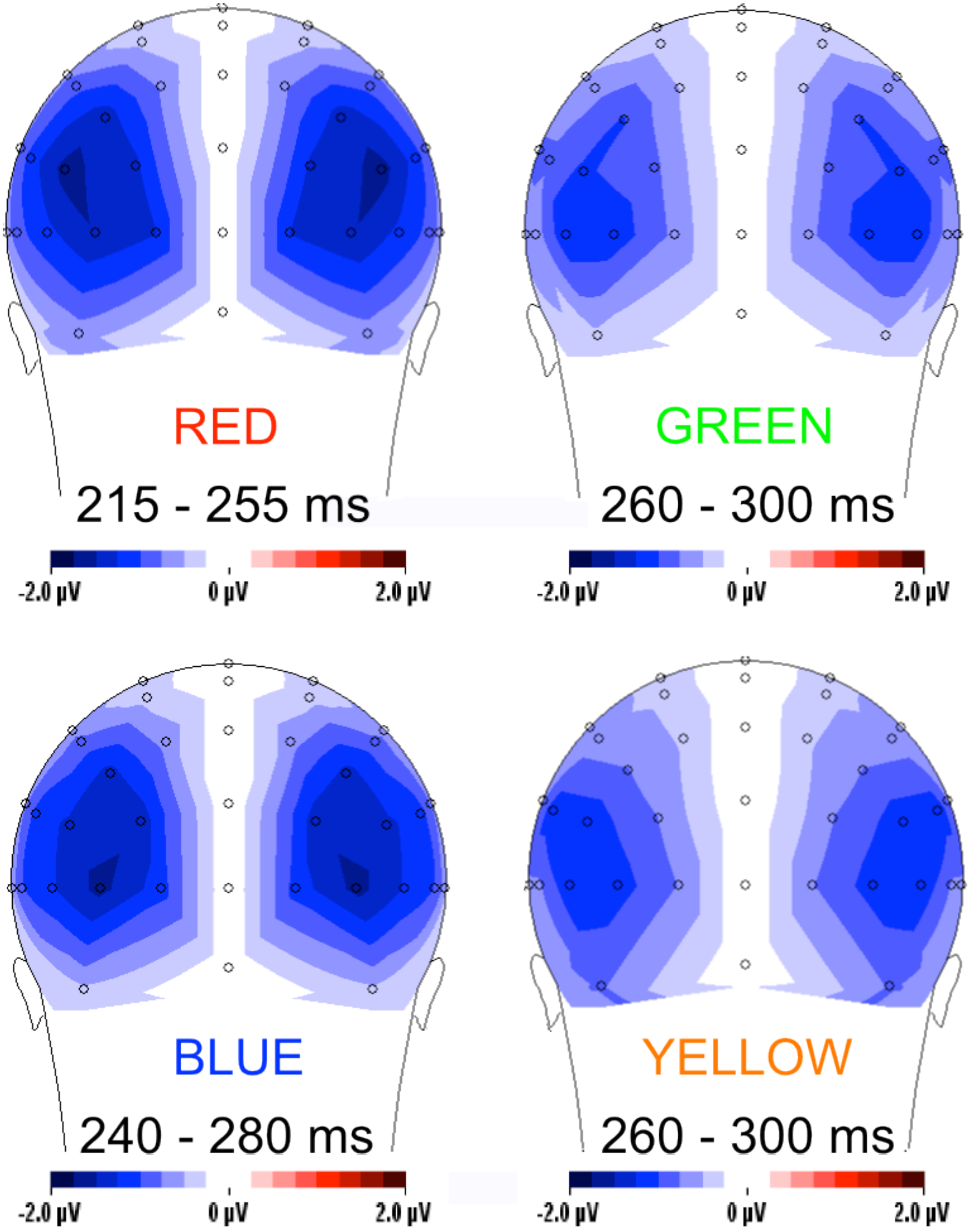

RED
215 - 255 ms
-2.0 µV
0 µV
2.0 µV
GREEN
260 - 300 ms
-2.0 µV
0 µV
2.0 µV
BLUE
240 - 280 ms
-2.0 µV
0 µV
2.0 µV
YELLOW
260 - 300 ms
-2.0 µV
0 µV
2.0 µV

Figure 7

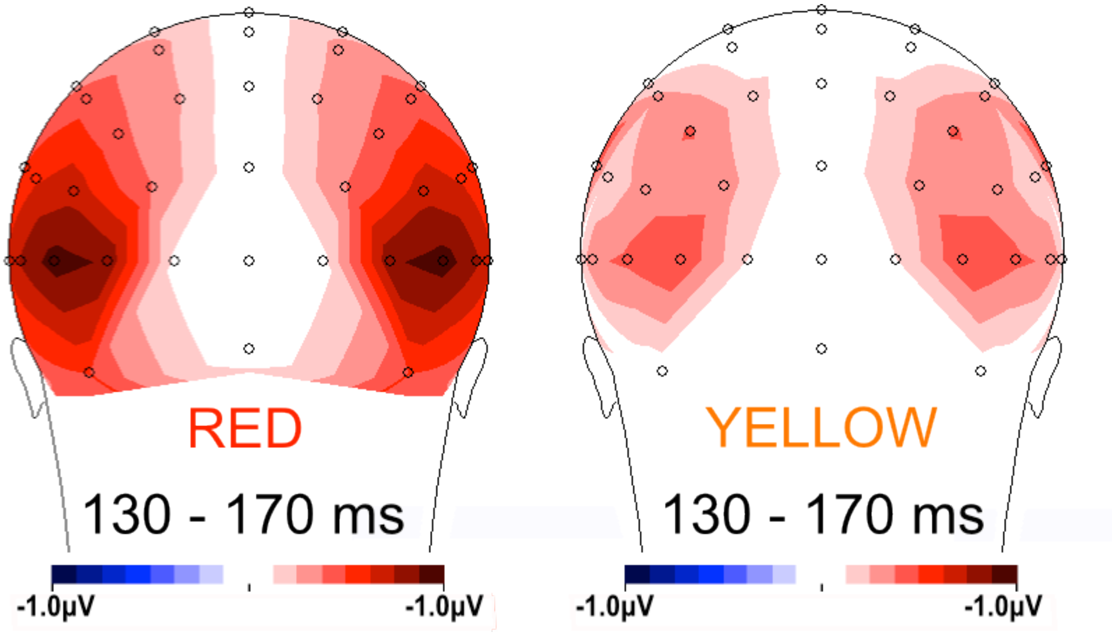


Figure 8

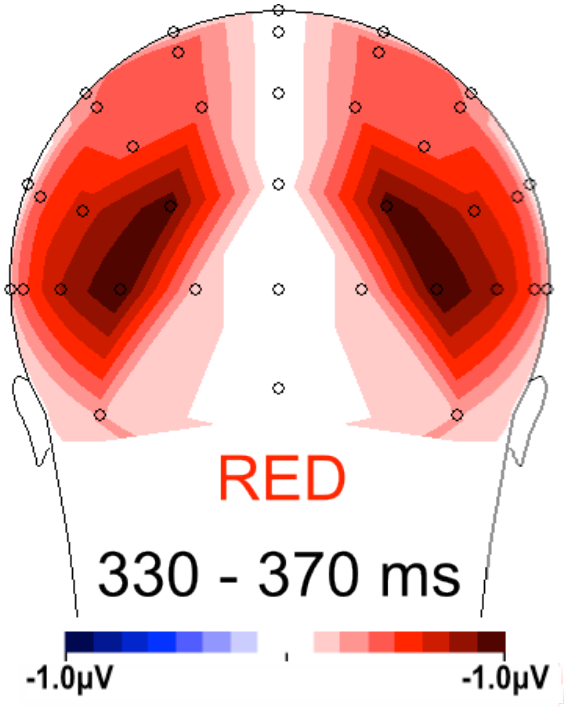


Figure 9

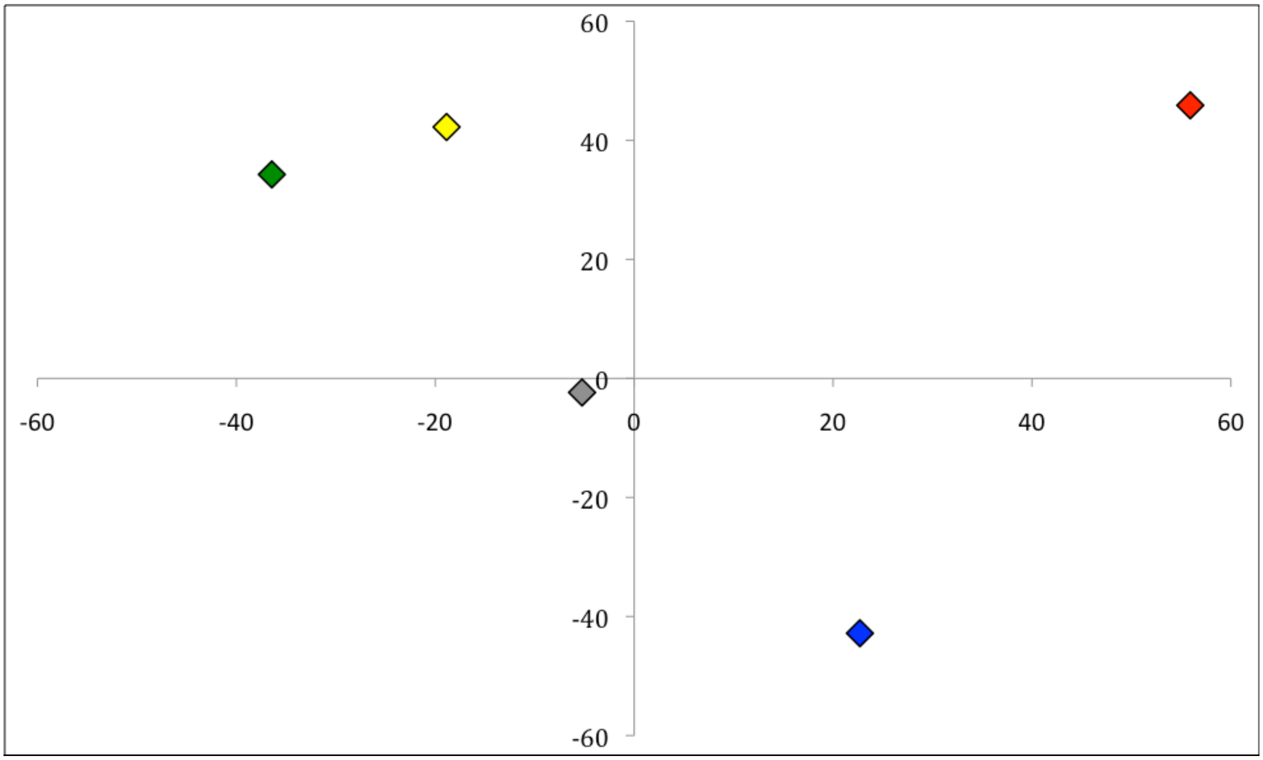
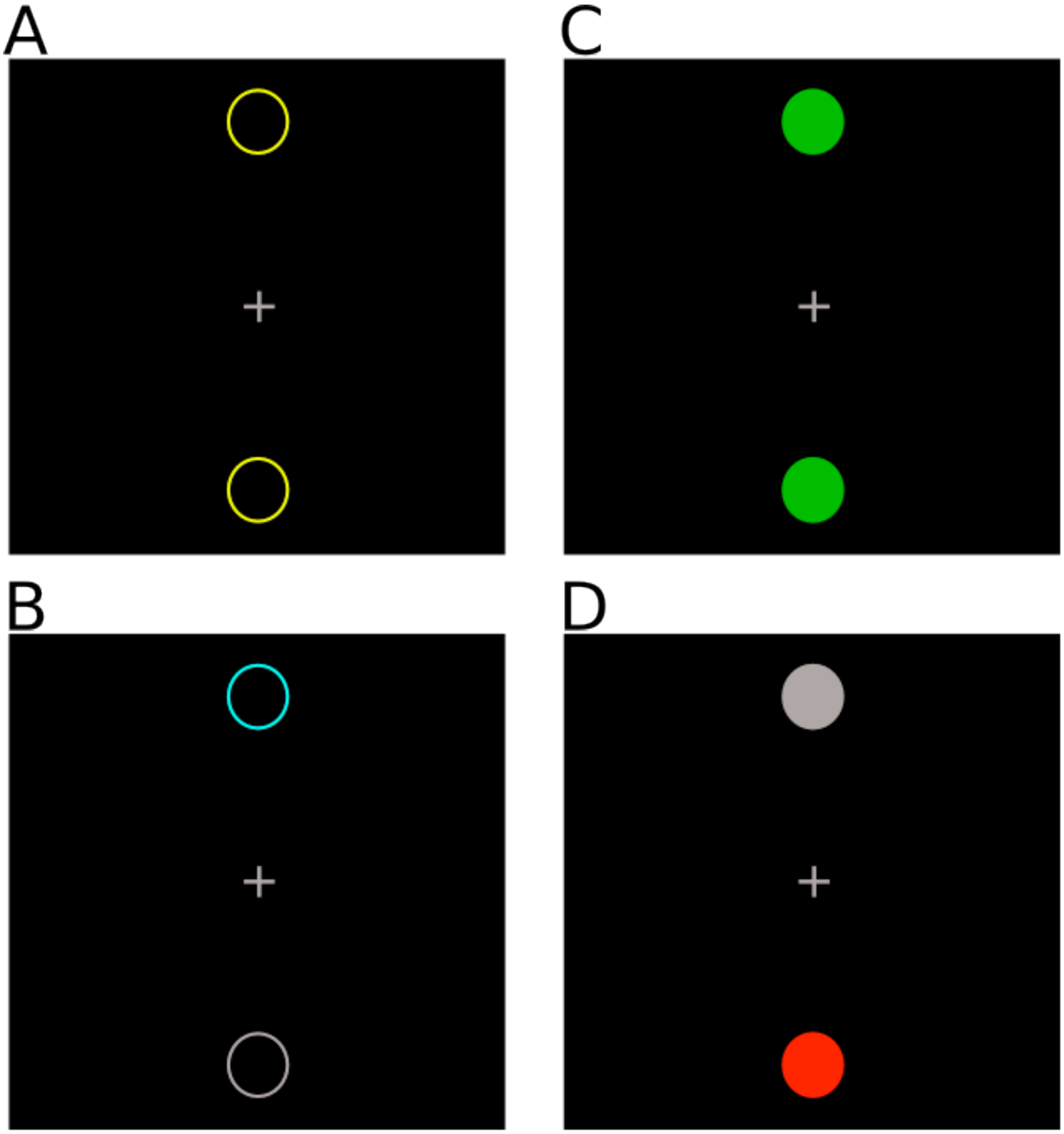


Figure 10



Discussion

L’influence de la couleur d’une cible sur les mécanismes attentionnels et préattentionnels a été étudiée par la méthode des potentiels évoqués dans l’expérience 1. Plus exactement, cette expérience s’est penchée sur le rôle de la couleur dans le déploiement attentionnel. Afin de clarifier ce rôle, une tâche de recherche visuelle avec cibles ou leurres de couleur différente (rouge, vert, bleu ou jaune) a été créée. Les cibles et leurres étaient placés parmi des stimuli de fond (gris), tous équiluminants, et obtenus via une calibration psychophysiologique. La tâche du sujet était de trouver le nombre de cibles parmi les leurres lors d’une présentation de six tableaux de recherche visuelle. Deux expériences contrôles (expériences 2a et 2b) ont évaluées la discriminabilité des différentes couleurs avec le gris. Le design de l’expérience a laissé comme seule possible cause des effets observés l’attention et les effets spécifiques aux couleurs.

Trois conclusions peuvent être formulées à partir des résultats. Premièrement, il a été démontré que des stimuli bleus ou rouges suscitent une N2pc plus précoce à celles des stimuli jaunes ou verts (rouge et bleu < jaune et vert). Deuxièmement, ces résultats ne peuvent être expliqués par une plus grande discriminabilité d’une couleur par rapport à une autre, tel que démontré par les résultats des deux tâches contrôles (Expérience 2a et 2b). Ces tâches n’ont en effet pas indiqué de différences significatives dans les TRs entre les différentes couleurs pour la condition *différente*. Troisièmement, une amplitude plus élevée pour les composantes Ppc et Ptc des stimuli rouges suggère une plus grande capture attentionnelle pour cette couleur.

Nos résultats concernant la latence de la N2pc confirment partiellement notre première hypothèse en plus de répliquer et d'approfondir de précédents résultats (Fortier-Gauthier, et al., 2013). La hiérarchie de couleur ainsi obtenue par les latences diffère de celles obtenues précédemment (Lindsey, et al., 2010; Tchernikov & Fallah, 2010). En effet, une différence importante ressort de nos résultats, la latence courte pour les cibles bleues. Il est intéressant de constater que la même hiérarchie obtenue pour la N2pc a été retrouvée pour la PPC. Ces résultats sont toutefois obtenus après des manipulations expérimentales plus étendues (voir plus haut). Toutefois, de par ces résultats, on peut conclure qu'un mécanisme attentionnel spécifique à la couleur s'enclenche avant le début de la N2pc.

Plusieurs hypothèses pourraient expliquer les différences observées entre les deux hiérarchies de couleur. Premièrement certaines couleurs pourraient être plus discriminables du gris. Nos tâches contrôles évaluaient cette possibilité, en mesurant la capacité à discriminer deux disques (2a) ou cercles (2b) en tant que *pareil* ou *différent.*

La condition *pareille* consistait en une présentation simultanée de deux stimuli de la même couleur (rouge, vert, bleu, jaune ou gris). La condition *différente* consistait en une présentation simultanée d'un cercle gris et d'un autre cercle rouge, vert, bleu ou jaune. Nos résultats ont confirmé l'absence de différences dans la discriminabilité entre les différentes couleurs de par l'absence de différences significatives pour la condition *différente*, reproduisant le contraste de couleur présent dans notre expérience électrophysiologique. De plus, les moyennes (voire table 6) vont contre cette hypothèse, puisque la couleur bleue a les TRs les plus lents, ce qui aurait été lié à une plus longue latence pour cette N2pc. Un facteur de discriminabilité ne peut donc expliquer les latences observées avec la N2pc dans la tâche électrophysiologique.

La condition *pareille* a été ajoutée à l'expérience contrôle afin d'avoir une tâche avec deux réponses possibles. L'objectif principal de la tâche contrôle était donc lié à la condition *différente.* Les différences découvertes dans la condition *pareille* (rouge<bleu) sont difficilement explicables et demandent davantage d'approfondissement.

Un autre facteur qui pourrait expliquer les différence avec les hiérarchie habituelles serait un bleu non équiluminant, expliquant ainsi sa latence plus courte. Cette hypothèse ne peut toutefois être retenue pour deux raisons. Premièrement, les valeurs de luminance après ajustement ont été mesurées à l'aide d'un instrument et soumises à des analyses statistiques. Ces valeurs de luminance ne différaient pas significativement entre elles. Deuxièmement, Cavanagh et ses collègues (1987) ont démontrés que la contribution des cônes bleus de la rétine est beaucoup plus faible que celles des deux autres types de cônes. Ceci diminue la probabilité que les différences de luminance entre cibles bleues et jaunes ou vertes soient la cause principale des différences observées entre les couleurs. La possibilité d'une couleur bleue non équiluminante comme explication de la hiérarchie actuelle est donc rejetée.

Une autre hypothèse pour expliquer notre hiérarchie de couleur fait appel à la séparabilité linéaire entre les couleurs. (Bauer, et al., 1996). Dans notre expérience, seulement deux dimensions doivent être considérées dans l'espace de couleur CIE L*ab, puisque toutes les couleurs étaient équiluminantes (la luminance étant une des trois dimensions). De plus, comme une seule couleur était présente à chaque recherche visuelle, la création (ou l'activation) d'une seule séparation linéaire était suffisante pour accomplir la tâche. La création/activation à chaque essai d'une ligne entre deux points différents dans un espace bidimensionnel étant toujours possible, une séparation était toujours possible entre couleur et stimuli de fond, permettant de bien effectuer la tâche.

Toutefois, malgré cette création/activation toujours possible, est-il envisageable que la création/activation d'un séparateur soit plus rapide avec les couleur associées à un déploiement attentionnel plus tôt (les couleurs bleu et rouge)? Cette possibilité est rejetée sur la base des résultats aux tâches comportementales (expériences 2a/2b). En effet, les résultats à la condition *différente* des deux tâches contrôle indiquent que la création/activation d'une séparation linéaire -ou de tout autre filtre- n'est pas plus rapide pour aucune couleur. Cette hypothèse ne peut donc être retenue. Ces résultats sont aussi très intéressants lorsque considérés avec les résultats concernant la Ppc. En effet, les expériences 2a et 2b démontrent que les différences en amplitude pour la composante Ppc ne peuvent être expliquées par des facteurs menant automatiquement à des TRs plus courts (i.e. luminance ou discriminabilité), ce qui aurait été le cas avec des différences significatives entre les conditions des expériences 2a/2b.

Dans le même ordre d'idée, un autre facteur qui pourrait expliquer la hiérarchie de couleur est une plus grande distance dans l'espace de couleur entre le gris et les cibles rouges/bleues versus le gris et les cibles jaunes/vertes. Ceci rendrait donc le jaune et le vert moins discriminables que le rouge et le bleu. En effet, une augmentation de la distance entre cible et distracteur dans l'espace de couleur résulte en un moins grand ralentissement des TRs lors de l'ajout de distracteurs (Bauer, et al., 1996, page 1453 & 1464). Ainsi, les cibles dont la couleur est la plus éloignée de celle du distracteur ont un coût d'ajout moindre en TR suite à l'addition de distracteurs par rapport aux cibles plus près du distracteur. La figure 9 illustre dans un espace bi-dimensionnel une moyenne des couleurs utilisées dans l'expérience électrophysiologique. L'espace utilisé est CIE L*ab, créé pour refléter autant que possible les différences dans la perception des couleurs chez l'humain. La figure 9 montre clairement des différences entre les différentes distances couleurs-gris. Une hypothèse pour expliquer nos résultats pourrait résider dans ces différences. Cette hypothèse pourrait expliquer l'avantage du rouge par rapport aux autres couleurs, ce dernier étant plus distant du gris. Toutefois, cette hypothèse présente un défaut majeur, le fait que la distance entre le gris et le bleu, le jaune et le vert est la même. Ainsi, puisque les cibles rouges et bleues entrainent une N2pc de latence similaire, cette hypothèse ne peut être pas retenue. De plus, le seuil nécessaire à la perception de couleurs différentes dans l'espace CIE L*ab est très faible (Allen L. Nagy, Robert R. Sanchez, & Thomas C. Hughes, 1990; Olds, et al., 1999). Considérant les couleurs représentées à la figure 9, il est très peu probable qu'un facteur de distance explique les différences électrophysiologiques, puisqu'un effet plafond de distinction couleur-gris est probablement atteint.

Il en résulte qu'aucune hypothèse cognitive ne semble expliquer l'ensemble de nos résultats. Précédemment, d'autres auteurs ont formulé des hypothèses évolutionnistes (i.e.

la pertinence de rapidement déployer son attention aux lèvres (rouge désaturé) permettrait possiblement un meilleur avantage pour la communication et ainsi la survie) ou encore en lien avec la proportion des cônes dans la rétine (cônes rouges > cônes verts >cônes bleus) afin expliquer leur hiérarchie de couleur et l'importance du rouge (Lindsey, et al., 2010; Tchernikov & Fallah, 2010). Ces hypothèses, sans être rejetées, ne peuvent être retenues pour expliquer nos résultats, en raison de la présence d'une courte latence pour la N2pc aux cibles bleues. Les présents résultats reflètent donc soit une variable non contrôlée dans notre expérience, soit un manque dans la littérature actuelle. Malgré ceci, les résultats précédents démontrent qu'un contrôle de la luminance ne résulte pas en l'annulation de tous les effets liés aux couleurs en électrophysiologie.

Certaines découvertes anatomiques aident à mieux comprendre nos résultats. La voie koniocellulaire, décrite dans les années 1940, a longtemps été sous-estimé dans son apport à la vision des couleurs. De nouvelles données lient la voie koniocellulaire aux cônes bleus et à de multiples zones du cortex visuel primaire, incluant des régions sélectives à la couleur chez les primates(Hendry & Reid, 2000; Komatsu, 1998). Ceci remet en perspective le rôle de cette voie dans la perception de la couleur (Chatterjee & Callaway, 2002; Martin, et al., 1997). Ainsi nos résultats pourraient refléter une intégration rapide de la voie koniocellulaire, transportant l'information sur les stimuli bleus dans la vision des couleurs. De telles hypothèses ont déjà été émises dans l'intégration du mouvement par les voies magnocellulaires et koniocellulaires (Morand, et al., 2000). La raison pour laquelle cette intégration se reflète seulement en électrophysiologie reste par contre inconnue.

La deuxième conclusion des expériences précédentes vient des tâches contrôles.

Il y a toutefois un écart entre les données comportementales et électrophysiologiques. Dans les tâches électrophysiologiques, une hiérarchie dans le déploiement attentionnel est observée, mais, dans une tâche comportementale similaire, aucune hiérarchie ne l'est. Dans le but de clarifier les résultats, les deux tâches seront comparées.

Les deux tâches présentaient des cercles de couleur obtenus par la même procédure de calibration et présentés à la même excentricité d'une croix de fixation. Comme ses facteurs étaient les mêmes, ils ne peuvent expliquer les différences. Ce qui diffère entre les deux tâche sont 1) le nombre de stimuli, 2) la nature de la tâche et 3) la distance entre les stimuli de couleur et les stimuli de fond. Concernant le nombre de stimuli, une des raisons pouvant entraîner les différences entre les expériences est une différence de stratégie entre les tâches. Toutefois, les stimuli utilisés pour les expériences différaient tous grandement du gris (voir figure 9). Pour cette raison, un changement de stratégie est peu probable (Bauer, et al., 1996). En effet, les items étaient fort probablement en condition de pop out par rapport aux items gris. Dans de telles situations, la différence entre 2 et 10 items affecte très peu la stratégie employée (Allen L. Nagy, et al., 1990; Treisman & Gelade, 1980). Aussi, concernant la différence dans la nature de la tâche, les expériences 2a et 2b, demandant une simple discrimination de couleur et sont donc plus facile que l'expérience 1, qui demande en plus d'une telle discrimination une identification de l'orientation d'une ligne. Ceci pourrait faire en sorte que moins de ressources attentionnelles soient déployées pour les expériences 2a/2b, expliquant l'absence de différence significative. Enfin, concernant la distance entre chaque cible et stimuli de fond, celle-ci aurait tendance à ralentir les TRs pour des distracteurs plus près des cibles (Mazza, et al., 2009b). Cet effet sur les TRs n'a pas été associé avec un effet sur l'amplitude ou sur la latence de la N2pc. Ceci éliminerait les probabilités que ce facteur soit tributaire des différences observées entre les expériences 2a/b et 1. Cet effet devrait aussi être sélectif de la couleur, ce qui n'a pas été rapporté.

Globalement, la conclusion principale est que les différences entre les tâches contrôle et la tâche électrophysiologique seraient probablement causées par des différences dans la demande attentionnelles des deux tâches. Malgré ceci, les résultats de la tâche contrôle confirment que tous les stimuli de couleurs sont également discriminables du gris et donc non responsable de l'effet de latence observé sur la N2pc.

Le troisième résultat principal suggère une préférence attentionelle pour les cibles rouges, puisque celles-ci évoquent une Ppc et une Ptc plus positive. En effet, les résultats concernant la Ppc montrent que la composante est plus positive pour les cibles rouges que les cibles bleues ou vertes. Ceci suggère un débalancement dans l'hémichamps visuel plus important pour les cibles rouges que les cibles des deux autres couleurs. Ceci pourrait expliquer les effets observés par plusieurs auteurs en recherche visuelle d'items de couleur (Lindsey, et al., 2010; Tchernikov & Fallah, 2010). L'absence de différence significative entre la Ppc rouge et jaune ne reflète pas les différences observées pour les composantes N2pc et Ptc.

Les études antérieures concernant la Ptc n'avaient pas jusqu'à présent pas considéré la couleur comme facteur expérimental. Bien que la saturation des couleurs ait été évaluée auparavant, différentes couleurs n'avaient pas été comparées(Hilimire, et al., 2010). Les hypothèses actuelles concernant la Ptc suggère qu'une plus grande amplitude de la composante reflète une nécessité d'inhibition plus grande pour le système visuel dans le but d'isoler une cible. En partant de cette hypothèse, cela signifierait la nécessité d'une plus grande inhibition des distracteurs entourant une cible rouge après un déploiement attentionnel. Ceci est peu probable, puisque les distracteurs sont identiques entre les différentes couleurs et que le rouge est probablement la couleur la plus discriminable du gris étant donné sa distance dans l'espace CIE L*ab du gris. Ceci suggère donc que le rouge force à la fois un plus grand déploiement attentionnel et une plus grande inhibition

Globalement, ces résultats contribuent à confirmer que la Ppc reflète la représentation électrophysiologique d'un déséquilibre dans le champ visuel, et que cette composante n'est pas seulement due à des artéfacts de luminance.

Conclusion

Finalement, les résultats concernant la N2pc, la Ppc et la Ptc ainsi que les résultats aux tâches contrôles suggèrent une évaluation méticuleuse des facteurs chromatiques dans l'étude de l'attention visuo-spatiale. En effet, il a été démontré que l'équiluminance ne permet pas d'annuler tous les effets électrophysiologiques liés à l'utilisation de couleurs différentes. Dans l'avenir, nous espérons que ces résultats permettront d'améliorer la compréhension des mécanismes perceptuels et attentionnels du cerveau humain.

Références

Ansorge, U., & Becker, S. (2013). Contingent capture in cueing: the role of color search templates and cue-target color relations. *Psychological Research*, 1-13. doi: 10.1007/s00426-013-0497-5

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics, 55*(5), 485-496.

Bauer, B., Jolicoeur, P., & Cowan, W. B. (1996). Visual search for colour targets that are or are not linearly separable from distractors. *Vision Research, 36*(10), 1439-1466. doi: 10.1016/0042-6989(95)00207-3

Baylor, D. A., Nunn, B. J., & Schnapf, J. L. (1987). Spectral sensitivity of cones of the monkey Macaca fascicularis. *J Physiol, 390*, 145-160.

Bone, R. A., & Landrum, J. T. (2004). Heterochromatic flicker photometry. *Archives of Biochemistry and Biophysics, 430*(2), 137-142. doi: DOI: 10.1016/j.abb.2004.04.003

Brisson, B., & Jolicoeur, P. (2007). The N2pc component and stimulus duration. *NeuroReport, 18*(11), 1163-1166. doi: http://dx.doi.org/10.1097/WNR.0b013e3281e72d1b

Brisson, B., Robitaille, N., & Jolicoeur, P. (2007). Stimulus intensity affects the latency but not the amplitude of the N2pc. *NeuroReport, 18*(15), 1627-1630. doi: http://dx.doi.org/10.1097/WNR.0b013e3282f0b559

Buchsbaum, G., & Gottschalk, A. (1983). Trichromacy, Opponent Colours Coding and Optimum Colour Information Transmission in the Retina. *Proceedings of the Royal Society of London. Series B. Biological Sciences, 220*(1218), 89-113. doi: 10.1098/rspb.1983.0090

Carter, R. C. (1982). Visual search with color. *Journal of Experimental Psychology: Human Perception and Performance, 8*(1), 127-136. doi: http://dx.doi.org/10.1037/0096-1523.8.1.127

Cavanagh, P., MacLeod, D. I., & Anstis, S. M. (1987). Equiluminance: Spatial and temporal factors and the contribution of blue-sensitive cones. *Journal of the Optical Society of America, A, Optics, Image & Science, 4*(8), 1428-1438. doi: http://dx.doi.org/10.1364/JOSAA.4.001428

Chatrian, G. E. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activity. *Am J Electroencephalogr Technol, 25*, 83-92.

Chatrian, G. E., Lettich, E., & Nelson, P. L. (1988). Modified nomenclature for the "10%" electrode system. *J Clin Neurophysiol, 5*(2), 183-186.

Chatterjee, S., & Callaway, E. M. (2002). S cone contributions to the magnocellular visual pathway in macaque monkey. *Neuron, 35*(6), 1135-1146. doi: S0896627302008747 [pii]

Clark, S. E. (1969). Retrieval of color information from preperceptual memory. *Journal of Experimental Psychology, 82*(2), 263-266. doi: http://dx.doi.org/10.1037/h0028135

Corriveau, I., Fortier-Gauthier, U., Pomerleau, V. J., McDonald, J., Dell'Acqua, R., & Jolicœur, P. (2012). Electrophysiological evidence of multitasking impairment of attentional deployment reflects target-specific processing, not distractor inhibition. *International Journal of Psychophysiology*(0). doi: 10.1016/j.ijpsycho.2012.06.005

Cowan, N. (2000). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. [Comment/Reply]. *Behavioral and Brain Sciences, 24*(1), 87-185. doi: http://dx.doi.org/10.1017/S0140525X01003922

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. [Comment/Reply]. *Behavioral and Brain Sciences, 24*(1), 87-185. doi: http://dx.doi.org/10.1017/S0140525X01003922

De Valois, R. L., Abramov, I., & Jacobs, G. H. (1966). Analysis of Response Patterns of LGN Cells. *Journal of the Optical Society of America, 56*(7), 966-977. doi: 10.1364/JOSA.56.000966

Dell'Acqua, R., Dux, P. E., Wyble, B., & Jolicoeur, P. (2012). Sparing from the attentional blink is not spared from structural limitations. *Psychonomic Bulletin & Review, 19*(2), 232-238. doi: 10.3758/s13423-011-0209-3

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*(3), 225-234. doi: http://dx.doi.org/10.1016/0013-4694%2896%2995711-9

Fortier-Gauthier, U., Dell'acqua, R., & Jolicoeur, P. (2013). The "red-alert" effect in visual search: Evidence from human electrophysiology. *Psychophysiology, 50*(7), 671-679. doi: 10.1111/psyp.12050 [doi]

Hendry, S. H. C., & Reid, R. C. (2000). The koniocellular pathway in primate vision. [Review]. *Annual Review of Neuroscience, 23*, 127-153. doi: 10.1146/annurev.neuro.23.1.127

Hickey, C., Di Lollo, V., & McDonald, J. J. (2009). Electrophysiological indices of target and distractor processing in visual search. *Journal of Cognitive Neuroscience, 21*(4), 760-775. doi: http://dx.doi.org/10.1162/jocn.2009.21039

Hilimire, M. R., Mounts, J. R. W., Parks, N. A., & Corballis, P. M. (2009). Competitive interaction degrades target selection: An ERP study. *Psychophysiology, 46*(5), 1080-1089. doi: 10.1111/j.1469-8986.2009.00846.x

Hilimire, M. R., Mounts, J. R. W., Parks, N. A., & Corballis, P. M. (2010). Event-Related Potentials Dissociate Effects of Salience and Space in Biased Competition for Visual Representation. *PLoS ONE, 5*(9), e12677. doi: 10.1371/journal.pone.0012677

Hilimire, M. R., Mounts, J. R. W., Parks, N. A., & Corballis, P. M. (2011). Dynamics of target and distractor processing in visual search: Evidence from event-related brain potentials. *Neuroscience Letters, 495*(3), 196-200. doi: 10.1016/j.neulet.2011.03.064

Jolicoeur, P., Brisson, B., & Robitaille, N. (2008). Dissociation of the N2pc and sustained posterior contralateral negativity in a choice response task. *Brain Research, 1215*(0), 160-172. doi: 10.1016/j.brainres.2008.03.059

Kiesel, A., Miller, J., Jolicoeur, P., & Brisson, B. (2008). Measurement of ERP latency differences: A comparison of single-participant and jackknife-based scoring methods. *Psychophysiology, 45*(2), 250-274. doi: http://dx.doi.org/10.1111/j.1469-8986.2007.00618.x

Komatsu, H. (1998). Mechanisms of central color vision. *Current Opinion in Neurobiology, 8*(4), 503-508. doi: 10.1016/s0959-4388(98)80038-x

Lennert, T., Cipriani, R., Jolicoeur, P., Cheyne, D., & Martinez-Trujillo, J. C. (2011). Attentional Modulation of Neuromagnetic Evoked Responses in Early Human Visual Cortex and Parietal Lobe following a Rank-Order Rule. *Journal of Neuroscience, 31*(48), 17622-17636. doi: 10.1523/jneurosci.4781-11.2011

Lindsey, D. T., Brown, A. M., Reijnen, E., Rich, A. N., Kuzmova, Y. I., & Wolfe, J. M. (2010). Color Channels, Not Color Appearance or Color Categories, Guide Visual Search for Desaturated Color Targets. *Psychological Science, 21*(9), 1208-1214. doi: 10.1177/0956797610379861

Liu, Q., Li, H., Campos, J. L., Wang, Q., Zhang, Y., Qiu, J., . . . Sun, H.-j. (2009). The N2pc component in ERP and the lateralization effect of language on color perception. *Neuroscience Letters, 454*(1), 58-61. doi: 10.1016/j.neulet.2009.02.045

Luck, S. J., & Hillyard, S. A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance, 20*(5), 1000-1014. doi: http://dx.doi.org/10.1037/0096-1523.20.5.1000

Martin, P. R., White, A. J. R., Goodchild, A. K., Wilder, H. D., & Sefton, A. E. (1997). Evidence that Blue-on Cells are Part of the Third Geniculocortical Pathway in Primates. *European Journal of Neuroscience, 9*(7), 1536-1541. doi: 10.1111/j.1460-9568.1997.tb01509.x

Mazza, V., Turatto, M., & Caramazza, A. (2009a). An electrophysiological assessment of distractor suppression in visual search tasks. *Psychophysiology, 46*(4), 771-775. doi: http://dx.doi.org/10.1111/j.1469-8986.2009.00814.x

Mazza, V., Turatto, M., & Caramazza, A. (2009b). Attention selection, distractor suppression and N2pc. *Cortex, 45*(7), 879-890. doi: http://dx.doi.org/10.1016/j.cortex.2008.10.009

Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology, 35*(01), 99-115. doi: doi:null

Morand, S., Thut, G., Grave de Peralta, R., Clarke, S., Khateb, A., Landis, T., & Michel, C. M. (2000). Electrophysiological evidence for fast visual processing through the human koniocellular pathway when stimuli move. *Cerebral Cortex, 10*(8), 817-825. doi: http://dx.doi.org/10.1093/cercor/10.8.817

Nagy, A. L., Sanchez, R. R., & Hughes, T. C. (1990). Visual search for color differences with foveal and peripheral vision. *J. Opt. Soc. Am. A, 7*(10), 1995-2001.

Nagy, A. L., Sanchez, R. R., & Hughes, T. C. (1990). Visual search for color differences with foveal and peripheral vision. *J Opt Soc Am A, 7*(10), 1995-2001.

Olds, E., Cowan, W., & Jolicoeur, P. (1999). Stimulus-determined discrimination mechanisms for color search. *Attention, Perception, & Psychophysics, 61*(6), 1038-1045. doi: 10.3758/bf03207611

Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology, 32*(1), 3-25. doi: http://dx.doi.org/10.1080/00335558008248231

Regier, T., & Kay, P. (2009). Language, thought, and color: Whorf was half right. *Trends in Cognitive Sciences, 13*(10), 439-446. doi: http://dx.doi.org/10.1016/j.tics.2009.07.001

Robitaille, N., & Jolicoeur, P. (2006). Effect of cue-target interval on the N2pc. *NeuroReport: For Rapid Communication of Neuroscience Research, 17*(15), 1655-1658. doi: http://dx.doi.org/10.1097/01.wnr.0000236859.16457.34

Sperling, G. (1960). The information available in brief visual presentation. *Psychological Monographs, 74*(11, Whole No. 498), 29.

Tchernikov, I., & Fallah, M. (2010). A Color Hierarchy for Automatic Target Selection. *PLoS ONE, 5*(2), e9338. doi: 10.1371/journal.pone.0009338

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97-136. doi: http://dx.doi.org/10.1016/0010-0285%2880%2990005-5

Ulrich, R., & Miller, J. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology, 38*(05), 816-827. doi: http://dx.doi.org/10.1017/S0048577201000610

Von Wright, J. M. (1972). On the problem of selection in iconic memory. *Scandinavian Journal of Psychology, 13*(1), 159-171. doi: 10.1111/j.1467-9450.1972.tb00064.x

Walsh, J. W. T. (1953). *Photometry*. London: Constable and Company Limited.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review, 1*(2), 202-238.

Woodman, G. F., & Luck, S. J. (2003). Serial deployment of attention during visual search. *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), 121-138. doi: http://dx.doi.org/10.1037/0096-1523.29.1.121

Zhao, G., Liu, Q., Zhang, Y., Jiao, J., Zhang, Q., Sun, H., & Li, H. (2011). The amplitude of N2pc reflects the physical disparity between target item and distracters. *Neuroscience Letters, 491*(1), 68-72. doi: 10.1016/j.neulet.2010.12.066