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ACADÉMIE EUROPÉENNE INTERDISCIPLINAIRE DES SCIENCES
INTERDISCIPLINARY EUROPEAN ACADEMY OF SCIENCES

Lundi 3 octobre 2016 à 17h :
à la Maison de l'AX, 5 rue Descartes 75005 Paris

Conférence de Jérôme SACKUR, Professeur à l'Ecole Polytechnique
Directeur d'Études à l' École des Hautes Études en Sciences Sociales,
Laboratoire de Sciences Cognitives et Psycholinguistique/
Ecole Normale Supérieure Ulm
" *Temps, subjectivité et métacognition: nouvelles pistes de recherche empirique sur la conscience* "

Notre Prochaine séance aura lieu le lundi 7 novembre 2016 à 17h
à la Maison de l'AX, 5 rue Descartes 75005 Paris
Elle aura pour thème:

Assemblée générale annuelle de l'AEIS

ACADÉMIE EUROPÉENNE INTERDISCIPLINAIRE DES SCIENCES
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octobre 2016

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TABLE DES MATIERES

Prochaine séance : lundi 7 novembre 2016

Assemblée générale annuelle de l'AEIS

ACADEMIE EUROPEENNE INTERDISCIPLINAIRE DES SCIENCES
5, rue Descartes 75005 Paris

Séance du Lundi 3 octobre 2016 5 rue Descartes 75005 Paris à 17h

La séance est ouverte à 17h **sous la Présidence de Victor MASTRANGELO** et en la présence de nos collègues Gilbert BELAUBRE, Jean-Louis BOBIN, Alain CORDIER, Sylvie DERENNE, Jean-Félix DURASTANTI, Françoise DUTHEIL, Michel GONDRAN, Irène HERPE-LITWIN, Antoine LONG, Claude MAURY, Edith PERRIER, Jacques PRINTZ, Jean SCHMETS, Michel SPIRO, Jean-Paul TEYSSANDIER, Jean-Pierre TREUIL.

Etaient excusés François BEGON, Jean-Pierre BESSIS, Bruno BLONDEL, Michel CABANAC, Alain CARDON, Gilles COHEN-TANNOUDJI, Alain CORDIER, Juan-Carlos CHACHQUES , Daniel COURGEAU, Ernesto DI MAURO, Claude ELBAZ, Vincent FLEURY, Jean -Pierre FRANÇOISE, Robert FRANCK, Jacques HENRI-ROBERT, Dominique LAMBERT, Gérard LEVY, Jacques LEVY, Valérie LEFEVRE-SEGUIN, Pierre MARCHAIS, Anastassios METAXAS, Jacques NIO, Pierre PESQUIES, Alain STAHL, Jean VERDETTI.

Etaient présents en tant que membres correspondants: Marie Françoise PASSINI, Dominique PRAPOTNITCH

I. Présentation de notre conférencier le Pr Jérôme SACKUR

Le Pr Jérôme SACKUR possède une formation pluridisciplinaire entre philosophie et sciences cognitives qui a orienté ses travaux. Il est Directeur d'Études à l'École des Hautes Études en Sciences Sociales et Professeur à l'École Polytechnique. Il travaille au Laboratoire " *Sciences Cognitives et Psycholinguistique*" à l' École Normale Supérieure 29, rue d'Ulm, 75005 Paris .

1. Titres et Diplômes

- Habilitation à diriger des Recherches (Sciences Cognitives — École Normale Supérieure, 2012)
- DEA National de Neuropsychologie (Université Paul Sabatier, Toulouse, 2000)
- Doctorat de Philosophie (Paris 1, 1999)
- Agrégé de Philosophie (1991)
- Ancien élève de l'École Normale Supérieure (Ulm) (1988)

Formation Initiale : philosophie

- 1994–1999 Doctorat de philosophie à l'Université Paris 1, sous la direction du Professeur Christiane Chauviré. Mention Très Honorable avec les félicitations du jury. Titre de la thèse : « ***Opération et Description. La critique par Wittgenstein des théories de la proposition de Russell*** ». Jury : Jacques Bouveresse (Collège de France), Claude Imbert (École Normale Supérieure), Sandra Laugier (Université d'Amiens, IUF), Mathieu Marion (Université d'Ottawa, Canada).
- 1993-1994 Visiting Fellow, Harvard University (États-Unis), Département de Philosophie.
- 1988-1992 Premier et second cycles universitaires (philosophie) :
- 1992 : DEA : « La valeur d'usage : A. Smith, D. Ricardo, K. Marx » dir. P. Macherey (Paris 1).
- 1991 : Admis (21ème) à l'agrégation de philosophie.
- 1990 : Maîtrise : « Ens rationis et Nihil negativum, deux figures du Rien dans la Critique de la Raison Pure de Kant » dir. J.- F. Marquet (Paris 4).
- 1989 : Licence de philosophie, Paris 4.

- 1988 : Admis (11ème) à l'École Normale Supérieure (Ulm), Lettres et sciences sociales

Formation complémentaire : sciences cognitives

- 2013 Hypnose clinique : Premier cycle en hypnose clinique (3 – 8 octobre 2013, Association Française d'hypnose médicale, Jean Becchio & Pierre Lelong.)
- 2012 **Habilitation à diriger des recherches** « **Approches expérimentales de la conscience : perception, dynamique, métacognition** ». Jury : Michaël Herzog (EPFL, Lausanne), Régine Kolinsky (UBL, Bruxelles), Dominique Muller (Grenoble), Lionel Naccache (INSERM), Elisabeth Pacherie (CNRS).
- 2011 Bayesian Modeling for Cognitive Science (Amsterdam, 22-26 août 2011)-École d'été organisée par E.J. Wagenmakers & D. Lee
- 1999–2000 **DEA de Neuropsychologie (Université Paul Sabatier, Toulouse)** ;
- Stage sous la direction de **Stanislas Dehaene** (directeur de recherches, INSERM U334) et Laurent Cohen (Professeur, Service de Neurologie 1, Hôpital de la Salpêtrière). Titre du mémoire: ***«Amorçage sémantique inconscient chez le patient négligent dans une tâche de comparaison numérique*** »..

2. Bourses et distinctions

- Institut Universitaire de France, 2009 – 2014
- Boursier Arthur Sachs (Harvard University), 1994
- Boursier Jean Walter-Zellidja (Académie Française), 1993

3. Contrats de Recherche

- ANR « MetaStress » Principal Investigateur (2017 - 2020)
- ANR « DYNAMIND » Principal investigateur avec Sid Kouider (2010 –2014)
- ANR « Confidence » coordonnée par Elisabeth Pacherie (Institut Jean Nicod, CNRS) 2007-2010.

4. Postes d'Enseignement

- 2016 Professeur, École Polytechnique
- 2015 Directeur d'Études, École des Hautes Études en Sciences Sociales
- 2007 - 2015 Maître de Conférences, Département d'Études Cognitives, École Normale Supérieure
- 2002-2006 Maître de Conférences, Département de Philosophie, Université Nanterre – Paris-X
- 2000-2002 Agrégé Répétiteur, ENS Ulm, Département de philosophie.
- 1998-2000 ATER, UFR de Philosophie, Université Paris 1.
- 1997-1998 ATER, ENS Ulm, Département de philosophie
- 1994-1997 Allocataire Moniteur, Département de Philosophie, Université de Rennes 1
-

5. Publications:

Le Pr Jérôme SACKUR est l'auteur de nombreuses publications:

Deux Ouvrages **:** (1) J. Sackur (2005) Formes et faits. Analyse et théorie de la connaissance dans l'atomisme logique, Paris, Vrin. **(**2)J. Sackur, Ch. Chauviré (2003) Le Vocabulaire de Wittgenstein, Paris, Ellipses.

20 Articles de Psychologie/ Sciences cognitives dans des revues scientifiques à comité de lecture

4 Articles de Philosophie des sciences

6. Participation à des Conférences:

Depuis 2006, le Pr Jérôme SACKUR a été invité à 19 conférences internationales portant sur les sciences cognitives:

7. **Participation récente à des Séminaires :**

Depuis 2008 il a participé à 14 séminaires internationaux (Europe, Canada, Usa, Japon...) sur les sciences cognitives

8. **Conférences de Vulgarisation**

Depuis 2011 il a participé à 4 conférences de vulgarisation en France et au Canada

9. **Encadrement de rédactions de thèse, de masters en sciences cognitives comme en philosophie analytique... Participation à des Jury de thèses**

Il a encadré de nombreux étudiants pour leur rédaction de thèse, de mémoires (Masters...) et il a participé au jury de nombreuses thèses et autres diplômes.

10. **Charges et responsabilités administratives**

Il exerce (ou a exercé) également de nombreuses responsabilités administratives dans divers organismes dédiés aux sciences cognitives et à la philosophie tels que le Laboratoire de Sciences Cognitives et Psycholinguistique (LSCP, UMR 8554), le Département d'Études Cognitives (ENS), Département de Philosophie, Paris 10 – Nanterre.

II. Conférence du Pr Jérôme SACKUR

Résumé en français de la présentation de notre conférencier " ***Temps, subjectivité et métacognition: nouvelles pistes de recherche empirique sur la conscience*** "

La conscience est actuellement bien reconnue en tant que domaine légitime de recherche en psychologie cognitive et en neuroscience. Des résultats impressionnants sur la dimension perceptive de la conscience ont été obtenus: qu'est ce qui rend spéciale une perception consciente? Quels sont les mécanismes cognitifs et neurophysiologiques responsables du passage de l'inconscient au conscient? Quelle est la profondeur du processus des représentations inconscientes? Telles sont les questions à l'origine d'un vaste corpus de connaissances voire même d'une esquisse de consensus. Je vais cependant défendre le fait que la conscience perceptive n'est qu'une dimension du phénomène complexe de conscience. En m'inspirant des avancées récentes dans les domaines de l'exploration du psychisme et de l'introspection , je vais présenter quelques possibilités de pistes de recherche susceptibles d'approfondir notre compréhension de la conscience en suivant les dimensions du temps, de la subjectivité et de la conscience réflexive.

Un compte-rendu détaillé sera prochainement disponible sur le site de l'AEIS , http://www.science-inter.com.

Notre Président Victor MASTRANGELO procède ensuite à la clôture de cette riche séance.

Irène HERPE-LITWIN

Annonces

I. L'AEIS vous rappelle la disponibilité en téléchargement gratuit au format PDF de son ouvrage sur le thème du colloque AEIS-2014 "SYSTÈMES STELLAIRES ET PLANÉTAIRES- CONDITIONS D'APPARITION DE LA VIE" sur le site d'EDP-Sciences:
http://www.edp-open.org/images/stories/books/fulldl/Formation-des-systemes-stellaires-et-planetaires.pdf

II. Notre collègue Christian HERVE nous fait part d'un prochain colloque sur les politiques de santé publique le 17 novembre 2016 à la Faculté de Médecine Paris Descartes , 15 rue de l'Ecole de Médecine 75006 PARIS.

Renseignements sur le site http://www.medecine.parisdescartes.fr

Documents

Dans le cadre général des sciences cognitives, notre collègue Ernesto di MAURO nous confie :

p. 08 : une annonce de janvier 2011 parue sur le site http://www2.cnrs.fr/presse/communique/2089.htm relative à l'Evolution du cerveau d'Homo sapiens depuis 30 000 ans.

Pour illustrer la riche conférence du Pr Jérôme SACKUR nous vous proposons les articles suivants:

p. 10: issu du site http://www.lscp.net/persons/sackur/docs/Reyes2014.pdf un article de Gabriel REYES et Jérôme SACKUR intitulé " *Introspection during visual search*" paru dans la revue Consciousness and Cognition 29 (2014) pages 212–229

p.31: issu du site http://www.lscp.net/braware/publi/dimensions.pdf un article Jérôme SACKUR intitulé "*Two dimensions of visibility revealed by multidimensional scaling of metacontrast*" paru dans Cognition (2012), http://dx.doi.org/10.1016/j.cognition.2012.09.013

dépasser les frontières

Vous êtes ici :

CNRS > Presse > Communiqués de presse

Paris, 26 janvier 2011

Evolution du cerveau d'Homo sapiens depuis 30 000 ans

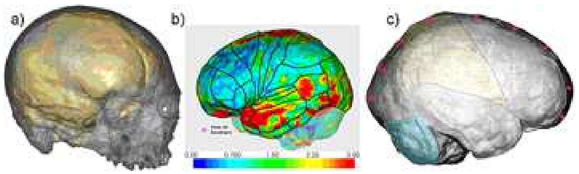
Une équipe pluridisciplinaire composée de chercheurs du Muséum national d'Histoire naturelle, du CNRS et de l'INRIA (1) présente pour la première fois une étude des modifications du cerveau au cours de l'évolution de notre espèce, Homo sapiens, depuis 30 000 ans. Les résultats de ce travail seront rendus publics le jeudi 27 janvier à 9h30 au Grand Amphithéâtre du Muséum dans le cadre des 1836èmes Journées de la Société d'Anthropologie de Paris (2).

Cro-Magnon, un « ancêtre » emblématique

Point de départ de cette étude, l'endocrâne du spécimen Cro-Magnon 1 a été reconstitué en 3 dimensions grâce aux méthodes d'imagerie puis imprimé physiquement par prototypage. L'endocrâne correspond à l'ensemble des empreintes laissées par le cerveau sur la surface interne du crâne, dont des veines, le réseau méningé ou les marques des différentes zones du cerveau. Cet endocrâne de Cro-Magnon 1 a été décrit et mesuré, ses asymétries quantifiées. Il a ensuite été comparé à tous les endocrânes d'*Homo sapiens* fossiles bien conservés découverts à ce jour, datés pour la plupart d'il y a environ 30 000 ans. Puis, ces spécimens fossiles ont été confrontés à un échantillon de 102 endocrânes d'Hommes actuels.

Plus petit, réorganisé, notre cerveau a évolué depuis 30 000 ans

Les principales spécificités du cerveau d'*Homo sapiens* se retrouvent chez tous les spécimens fossiles, y compris Cro-Magnon 1. Pourtant, les résultats obtenus illustrent aussi une diminution de la taille du cerveau et sa réorganisation chez notre espèce depuis 30 000 ans. Notre cerveau est plus court, plus bas, comprimé au niveau des lobes frontaux et occipitaux alors que les lobes temporaux et le cervelet se sont élargis, par rapport à nos prédécesseurs. Ceci démontre la plasticité anatomique du cerveau chez *Homo sapiens*, mais aussi combien les relations entre sa taille et sa forme et les capacités cognitives sont complexes.



Visuels : l'endocrâne de Cro-Magnon 1 reconstitué en 3 dimensions (en jaune) vu par transparence du crâne (a), asymétries de l'endocrâne de Cro-Magnon 1 et carte de Brodmann (b), modifications de forme de l'endocrâne

entre Cro-Magnon 1 (à l'extérieur) et un Homme actuel
« moyen » (à l'intérieur) (c).

Notes :

(1) Antoine Balzeau est chargé de recherche au CNRS (UMR 7194 Muséum national d'Histoire naturelle/CNRS), Florent Détroit et Dominique Grimaud-Hervé sont respectivement maître de conférences et professeur en paléoanthropologie du Muséum national d'Histoire naturelle (UMR 7194 Muséum national d'Histoire naturelle/CNRS), Benoît Combès et Sylvain Prima sont doctorant et chargé de recherche à l'INRIA (EPI VisAGeS), à l'INSERM (U746) et au sein du laboratoire IRISA (Université Rennes I/CNRS).

(2) 1836èmes Journées de la Société d'Anthropologie de Paris, du 26 au 28 janvier 2011, au Grand Amphithéâtre du Muséum, Jardin des plantes, 57 rue Cuvier, 75005 Paris.

(3) Le cerveau de Cro-Magnon 1 a d'abord pu être reconstitué en trois dimensions sur l'écran d'un ordinateur, puis grâce à des imprimantes en « 3D », un prototype en plastique de l'endocrâne a été produit. Voir le communiqué de presse du 8 mars 2011 intitulé « Une empreinte du cerveau de l'homme de Cro-Magnon reconstituée en 3D »

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Introspection during visual search

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A R T I C L E   I N F O

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A B S T R A C T

Recent advances in the field of metacognition have shown that human participants are introspectively aware of many different cognitive states, such as confidence in a decision. Here we set out to expand the range of experimental introspection by asking whether participants could access, through pure mental monitoring, the nature of the cognitive processes that underlie two visual search tasks: an effortless "pop-out" search, and a difficult, effortful, conjunction search. To this aim, in addition to traditional first order performance measures, we instructed participants to give, on a trial-by-trial basis, an estimate of the number of items scanned before a decision was reached. By controlling response times and eye movements, we assessed the contribution of self-observation of behavior in these subjective estimates. Results showed that introspection is a flexible mechanism and that pure mental monitoring of cognitive processes is possible in elementary tasks.

1. Introduction

Humans are endowed with introspection, the ability to monitor their own mind. For a long period in the history of experimental psychology this ability was viewed with some suspicion, mainly because introspection as a method for the investigation of cognitive functioning was largely unsuccessful (see a review in Boring, 1953; Costall, 2006; Danziger, 1980; Lyons, 1986; Sackur, 2009). However, since the recent re-conceptualization of introspection as an intrinsic feature of consciousness (Feest, 2012; Goldman, 2004; Piccinini, 2003), it has been reconsidered as a legitimate field in cognitive psychology (Jack & Shallice, 2001; Schooler, 2002; Schooler & Schreiber, 2004) and amenable to experimentation in neuroscience (Baird, Smallwood, Gorgolewski, & Margulies, 2013; Fleming & Dolan, 2012; Fleming, Weil, Nagy, Dolan, & Rees, 2010; Jack & Roepstorff, 2002).

Despite great progress in the science of introspection in recent years, an issue not yet resolved is: what mental content is accessible to introspection? In the wake of Nisbett and Wilson's seminal paper (Nisbett & Wilson, 1977), researchers have been very wary of the kinds of introspective reports they should elicit from their participants. Nisbett and Wilson gathered considerable empirical evidence and theoretical arguments to the effect that one should clearly distinguish reports on internal cognitive *states* as opposed to internal cognitive *processes*. While the former may, in some context, be introspectively accessed, the latter were deemed, by and large, inaccessible. Thus, asking participants about them would most often lead to confabulations. Nisbett and Wilson held that the process that links a stimulus and the response does not reach participants' consciousness, and that only cognitive products or states are consciously accessed (see also Neisser, 1967). Despite

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1053-8100/

initial substantial objections (Ericsson & Simon, 1980; Smith & Miller, 1978; White, 1980, 1987, 1988), and recent reformulations (Wilson, 2002, 2003), this idea is considered as a canon of the literature on metacognition (Johansson, Hall, Silkström, & Olsson, 2005; Overgaard, 2006; Overgaard & Sandberg, 2012).

In recent years, the set of responses that may qualify as introspective has considerably increased. Among these, traditional confidence ratings (e.g., Fleming et al., 2010; Pleskac & Busemeyer, 2010; Song et al., 2011) have been reconsidered in depth, and new ones, such as judgments of duration of perceptual decisions (Corallo, Sackur, Dehaene, & Sigman, 2008; Marti, Sackur, Sigman, & Dehaene, 2010; Miller, Vieweg, Kruize, & McLea, 2010) have come to the fore. However, it is important to note that all these new forms of introspection are reports on internal cognitive *states*, and thus all abide by Nisbett and Wilson's canon. In this paper, we seek to put this limitation under experimental scrutiny.

It is interesting to note that most cognitive processes that Nisbett and Wilson target are complex, high-level forms of reasoning. Recent advances in the field of introspection have all been achieved by focusing on elementary cognitive tasks. For instance, Corallo et al. (2008) and Marti et al. (2010) selected the well-studied *Psychological Refractory Period* paradigm, as a first order cognitive task, and asked participants to report the durations that they introspectively perceived while performing this task. Here, we ask whether participants are introspectively aware of a difference in the kinds of processes triggered by two well-attested first order experimental tasks.

We relied on the following basic paradigm: we instructed participants to perform a visual search task in two different conditions, one simple and fast, in which the target "pops out", the other being more difficult and requiring an effortful exploration of the visual scene. Concurrently, on a trial-by-trial basis, we collected quantitative introspective reports. Our aim was to assess whether these introspective reports correlated with differences in processing that we could infer from a third-person, external standpoint. We chose visual search as a first order task, as it is known that in this task minimal changes in the stimuli induce important changes in performance profiles, indicative of a switch between two modes of processing. Traditionally, searches were construed as either *parallel* or *serial* processes (Sternberg, 1966; Townsend, 1990). In visual search, Treisman's seminal Feature Integration Theory (FIT, Treisman & Gelade, 1980) contrasted *feature searches* and *conjunction searches*, the former producing parallel searches and the latter serial searches. This difference was meant to account for the empirical finding that in feature searches, mean Response Times (RTs) do not increase as the number of distractors is increased, while in conjunction searches, mean RTs increase linearly as a function of the number of distractors. FIT asserts that in feature searches the visual system extracts in parallel, pre-attentively, the set of basic characteristics of the scene, which are necessary and sufficient to select the response. On the contrary, in *conjunction searches* attention is deployed serially one item, or group of items, at a time.

A strict dichotomy between parallel and serial searches is no longer tenable (Eckstein, 2011). First, it has been known for a long time that linear increase in mean RTs is not diagnostic of serial processing (*model mimicking*, Townsend & Wenger, 2004). Second, it appeared that there is a continuum of more or less efficient searches (Thornton & Gilden, 2007; Wolfe, 1994, 2007; Wolfe, Cave, & Franzel, 1989). The current consensus is that inefficient visual searches exhibit prominently *capacity limits*, whereas efficient searches do not incur such limits. Furthermore, it is also widely admitted that easy, efficient searches evade capacity limits because they benefit from *guidance of attention* by features extracted from non-selective pathways (Wolfe, 2003; Wolfe & Horowitz, 2004; Wolfe, Võ, Evans, & Greene, 2011, but see Cameron, Tai, Eckstein, & Carrasco, 2004; McElree & Carrasco, 1999). Our objective was to test whether participants can introspectively access the presence or absence of capacity limits and of attentional guidance.

Of course, no decision process is ever absolutely without "capacity limits", and visual searches are no exception to this rule. For instance, Joseph, Chun, and Nakayama (1997) showed that even highly efficient pop-out searches are subject to capacity limits when performed in conjunction with an attention depleting dual task. This feature is nicely accounted for by dual stage models of visual search (Wolfe, 2003) where the second, response selection stage is viewed as a central decision stage, subject to bottleneck effects. The key point for us is that, in the absence of concurrent tasks, in efficient searches the response selection stage can benefit from parallel feature extraction performed during the first stage, through attentional guidance. Inefficient searches cannot benefit from attentional guidance, and thus always exhibit bottleneck effects that result in slower RTs with increasing set-size.

In all our experiments distractors were schematic Ts, while targets were either an X or an L. These stimuli are known to produce two clearly different search profiles. Without theoretical commitments, we will refer to searches of an X among Ts as Feature Searches (FS, targets defined by a single orientation feature), and to searches of an L among Ts as Conjunction Searches (CS, targets defined by the specific conjunction of two features that are also present in the distractors). After each decision on the search task, participants were instructed to report the number of items that they had scanned before giving their response, a measure that we termed "Subjective Number of Scanned Items" (SNSI). We predicted that participants' estimations would be constant and close to one item in FS, independently of the number of distractors on the screen. In contrast, we predicted higher SNSI scores in CS, and crucially, an increase as a function of set-size. One may think of this measure as the subjective counterpart to the "scanning process" of Sternberg's (1966) pioneering work on memory search.

Two important aspects of the SNSI measure should be emphasized here: first, this measure is an *index* of putative differences in processing. We did not ask our participants to report directly on the type of processes involved in a particular trial, but we reasoned that if there were any such introspectively accessible differences, they should show in the number of subjectively scanned items before the decision. Second, we expect our index to be analytical or pure (Sternberg, 2001), to the extent that it captures only one among presumably many different kinds of introspective information. That is, our SNSI index attempts to selectively isolate the introspective contribution of capacity limits in visual search. Note that Miller et al. (2010) already tried for a pure measure of subjective (introspective) decision *duration*.

However, even with this framing of the introspective task, we cannot rule out the contamination of SNSI responses by other introspective information (Goldman, 2004; Piccinini, 2003; Prinz, 2004). Contamination could occur strategically because, for instance, participants notice that SNSI correlates with duration and find duration easier to access; or it could occur unconsciously, as a bias in SNSI reports. Furthermore, we should allow for the possibility that the information that the SNSI targets might simply *not* be introspectively accessible. In this case, data from the SNSI scale would be purely experimental artifacts: since we force participants to select a value on the scale, they might comply and simply report something which they think (according to their theory of search processes) should correlate with SNSI. Indeed, this is the straightforward prediction from Nisbett and Wilson's confabulation model.

In order to meet these challenges, we adapted a multi-level mediational approach (Bauer, Preacher, & Gil, 2006) as an analytic strategy of *reliability* (Piccinini, 2003), trying to detect whether any effect found on the SNSI scale is explained away when behavioral variables (i.e., RTs and eye-movements) are taken into account. This approach distinguishes *self-observation* and *mental monitoring*. Knowledge about oneself, even about one's own mental processes, can derive both from direct access to mental processes, or through inferences based on self-observation of behavior. Both qualify as introspection in a broad sense, but only the first is pure introspection, which may be more adequately termed *mental monitoring*. While this distinction was clearly stated in Nisbett and Wilson's seminal paper, it may have been under-appreciated in more recent experimental studies of introspection. The mediational approach is aimed at weighting the relative contributions of mental monitoring and self-observation in an introspective task.

The first three experiments delineate the conditions under which participants are able to introspect on the search processes. We show that even though self-observation of response times could account for a significant portion of the introspective judgments, we can set-up experimental conditions that permit mental monitoring of the processes themselves. Next, in the last two experiments we try to insulate introspective judgments from the contaminants that we identified or suspected in the first experiments. In Experiment 4a, we factor out response times and we measure eye movements, while in Experiment 4b, we both control response times and eye movements.

2. Experiment 1

In this first experiment, we asked participants to detect a visual target in an array of distractors, and after each response, we asked them to report on a quantitative scale the number of items they felt they had scanned before they reached their decision (Subjective Number of Scanned Items, SNSI). In addition we also collected traditional introspective measures: confidence judgments and introspective response times (iRT).

2.1. Materials and methods

2.1.1. Participants

Thirteen normal adults, French speakers (10 women), aged between 20 and 29 (mean age: 24.3 years, *SD*: 3.5) participated in the study. In this, as in the experiments which follow, informed consent was obtained before the experimental session, and participants received compensation of €10 for each 1-h session. None of the participants had any knowledge regarding the study and all had normal or corrected to normal vision.

2.1.2. Stimuli

Stimuli (see Fig. 1) consisted of a set of black letters (T, L or X, size: 0.8° × 0.6°, luminance: 0.5 cd/m^2) on a uniform gray background (luminance: 44.1 cd/m^2), presented on an imaginary circle (radius: 6.2°) around a central fixation spot at the

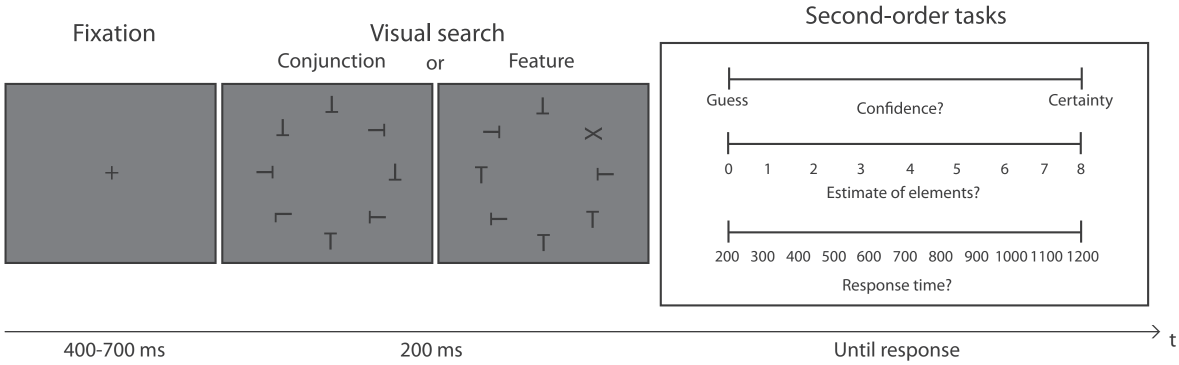

Fig. 1. General structure of the task in Experiment 1. The scales appeared immediately after participant's response on the first order, visual search task, and their position on the screen was fixed throughout the experiment. Instructions insisted on the fact that the "subjective number of scanned items" (SNSI) scale required a report of the number of items scanned *before* the identification of the target.

center of the screen. Individual orientation for each letter was randomized (0°, 90°, 180°, 270°). Stimuli were equally spaced on the imaginary circle, while its overall orientation was randomized for each trial. Stimuli were presented on a CRT screen (size 17″, resolution of 1024 × 768 pixels, refresh rate of 100 Hz, viewing distance ~55 cm). The experiment took place in a dark booth with the monitor as the only source of light.

2.1.3. Task and procedure

Stimuli were presented for 200 ms, preceded by a fixation spot presented for a duration drawn from the interval 400–700 ms. Participants were instructed to decide on the presence or absence of a target (L or X) within the set of distractors (Ts), by pressing as quickly and accurately as possible, with the index and middle fingers of their left hand, either the "A" or "Z" key on a standard AZERTY French keyboard. Half of the trials were target absent trials, with only distractors. Target present trials contained one "L" or one "X". Set-size (2, 4, 8 or 12 items, including target if present) and presence or absence of a target were fully crossed. Immediately after the perceptual decision, three continuous introspective scales were presented within the same display: (i) *Confidence*: Are you certain of your decision? Labeled at the two extremes with "guess" and "absolutely certain"; (ii) *Subjective Number of Scanned Items* (*SNSI*): How many items do you think you examined before reaching your decision? This scale ranged from a minimum of "0"to a variable maximum, equal to the set-size of the trial; (iii) *Introspective estimate of the response time* (*iRT*): How long do you think that it took you to determine whether the target was present or absent? This was a graduated scale ranging from 200 ms to 1200 ms with marked intervals of 100 ms.

Position of the scales on the screen was constant during the experiment. Participants used their right hand to move the cursor with the computer mouse, and click on the scales to give their quantitative introspective estimates. Meaning and use of the introspective scales was explained before the main experiment, while during the experiment instructions were presented in an abbreviated manner below the scales. Participants were instructed to avoid fast or automated responses.

Before the experimental blocks participants received two-stage training. During the first stage of 16 trials the visual search task, with a lengthened duration of 800 ms, was presented without the introspective scales but with audio feedback on correct and incorrect responses. This phase was repeated until participants reached a performance of 90% correct. The second training, also comprising 16 trials, introduced the introspective scales. Feedback was given on the response time estimate: a blue bar above the scale, which indicated the objective response time, after the participant's estimate had been given. During the second stage, the primary task was presented at 200 ms and participants proceeded to the main experimental block without the performance criterion. The experimental session comprised 480 trials (120 repetitions per search condition) in 10 blocks with a 60 s pause between blocks. The experimental session lasted ~1 h.

2.1.4. Training session

The day before the experimental session, participants took part in a training session (480 trials, one hour) which was in all respects identical to the main experimental session with the exception that target types were blocked.

2.2. Results

2.2.1. First order task

First, we wanted to verify that the two search conditions were opposed as regards capacity limitation, as is classically reported in the literature. We excluded trials with response times below 200 ms and trials with response times 3 *SD* above the median (3.8%).

Here, and in all following analyses, we used Linear Mixed Models (LMMs) with fixed effects of search type (feature search, FS *versus* conjunction search, CS), set-size (2, 4, 8, 12) and their interactions. As random effects the models included intercepts and a random slope for set-size for each participant. In all LMMs we used the restricted maximum likelihood (REML) as fitting method.

Response times and error rates were correlated (present target trials: $r^2(103) = .30$, $\beta_{Stand.} = .55$, $t = 6.58$, $p < .001$; absent target trials: $r^2(51) = .21$, $\beta = .46$, $t = 3.64$, $p < .01$, see Fig. 2A). Thus, we computed an Inverse Efficiency Scores (IES: ratio of median RTs over proportion of correct responses, see Austen & Enns, 2003; Bruyer & Brysbaert, 2011; Townsend & Ashby, 1983), which provides a concise summary of the first-order results. Lower values correspond to better performance. Before calculating IES, RTs were log-transformed to approximate normal distribution.

We found the pattern of interaction between target type and set size (see Fig. 2B), which is typical of the opposition of capacity limited and non-capacity limited searches. We ran an LMM on IES on target present trials, and found that the two main effects were significant (search type: $F(1,84.5) = 4.72$, $p < .05$, the set-size: $F(1,11.6) = 4.73$, $p < .05$) as well as the interaction ($F(1,84.8) = 8.22$, $p < .01$). A more detailed examination indicated that while in CS, IES increased as a function of set-size ($F(1,12.0) = 7.79$, $\beta = .28$, $p < .05$), it was constant in FS ($p > .53$). When the analysis was repeated on the trials without a target, a significant increase of IES by set-size was shown ($F(1,13.8) = 7.19$, $\beta = .72$, $p < .05$). IES in these trials was higher than in target present trials ($F(1,88.7) = 38.12$, $p < .001$). In sum, these results validate the choice of targets and distractors: searching an L among Ts is increasingly difficult with increasing set-sizes compared to searching an X among Ts. This lends support to the idea that searching an L is capacity limited as opposed to the search for an X.

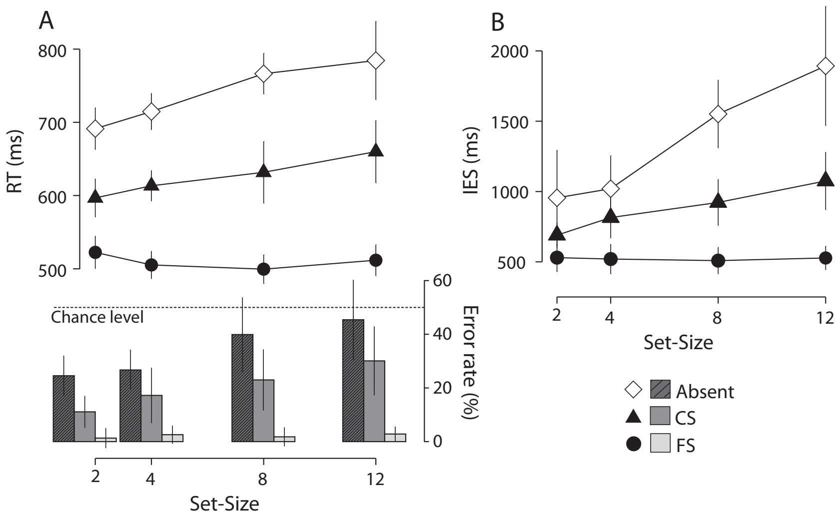

Fig. 2. First order results of Experiment 1 (A) Response times and Error rates as a function of set size in both visual search conditions and absent target trials. Error bars, here and in the following experiments, are Cousineau-Morey within-subjects 95% confidence intervals (Cousineau, 2005; Morey, 2008), calculated separately for present and absent target trials. (B) Inverse efficiency scores (IES) as a function of set size in CS, FS and absent target trials.

2.2.2. Second order task

After each first order response, participants gave three second order responses: confidence, introspective response time (iRT), and subjective number of scanned items (SNSI), this last response being the focus of our investigations. All *p* values were Bonferroni corrected (*p*(cor)), to account for the 3 dependent variables.

Confidence decreased in CS as a function of set-size, but stayed high for FS at all set-sizes (see Fig. 3A). This was confirmed statistically: we ran the previous LMM on mean confidence index (anchored at 0 and 1), which showed a significant main

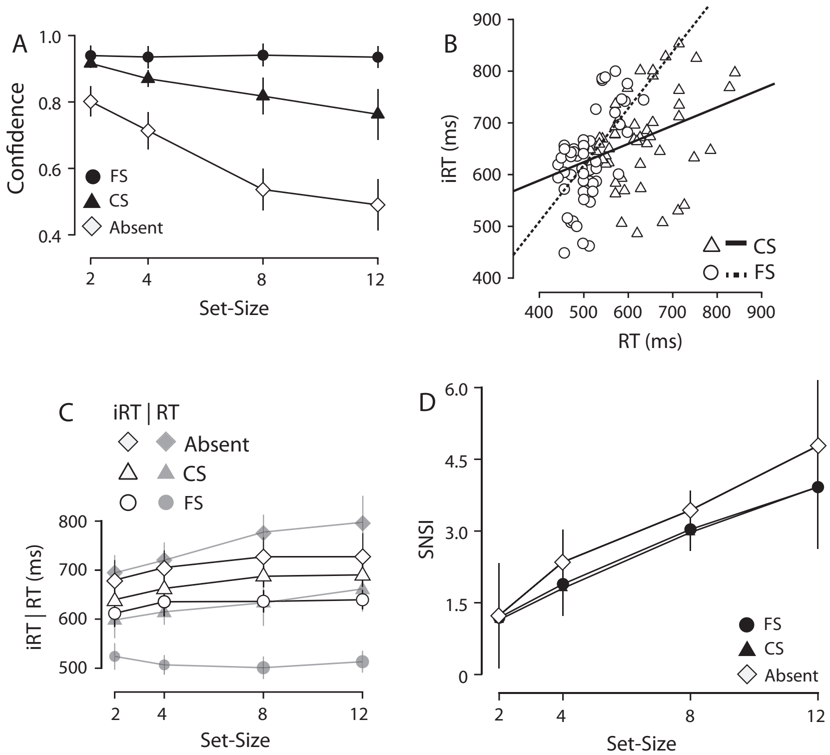

Fig. 3. Second order results of Experiment 1 (A) Confidence index as a function of set-size in both search conditions and absent target trials. (B) Linear regression of mean RT on mean iRT in CS and FS condition and (C) iRT (black lines) and RT (gray lines) as a function of set-size in both search conditions and absent target trials. (D) SNSI as a function of set-size in CS, FS and absent trials.

effect of set-size ($F(1,12.2) = 11.32$, $p(\text{cor}) < .05$), no effect of search type, ($p(\text{cor}) > .45$), and a significant interaction between these factors ($F(1,81.4) = 16.43$, $p(\text{cor}) < .001$). Importantly, we found a significant and negative slope for CS ($F(1,12.0) = 13.40$, $\beta = -.01$, $p(\text{cor}) < .01$), while it was not significant in FS ($p(\text{cor}) > .54$). In absent trials, the confidence index significantly decreased as a function of set-size ($F(1,90.0) = 16.13$, $\beta = -.02$, $p(\text{cor}) < .001$).

Next, we regressed iRT (see Fig. 3B and C) on RT, across correct-present individual trials, for each search condition separately. The regression slope was different from zero in both conditions (CS: $r^2(1199) = .13$, $\beta = .34$, $SE = .02$, $p(\text{cor}) < .001$; FS: $r^2(1517) = .16$, $\beta = .58$, $SE = .03$, $p(\text{cor}) < .001$), indicating that participants could access their response times in each search condition. The difference between these two slopes was significant, ($F(3,2717) = 173.1$, $\beta = .23$, $SE = .04$, $t = 5.60$, $p(\text{cor}) < .001$), which indicates a better introspective access of RTs in FS than CS. The same regression on trials without a target yielded a significant slope ($r^2(1956) = .07$, $\beta = .24$, $SE = .07$, $p(\text{cor}) < .01$). In sum, results on these two second-order tasks show that participants have introspective knowledge about their performance.

Now we come to the subjective number of scanned items (SNSI), which tracks the subjective accessibility of capacity limitations during the search. SNSI increased as a function of set-size (see Fig. 3D), but did not reveal any difference between search conditions. Set-size effects were found both in target present trials ($F(1,12.0) = 6.73$, $p(\text{cor}) < .05$) and in target absent trials ($F(1,12.0) = 8.53$, $p(\text{cor}) < .05$). No other main effects or interaction were significant. This suggests a general effect of the number of items displayed, without introspective access to the difference in the search processes involved.

2.3. Discussion

In agreement with the extensive literature on visual search, we found that a target with a distinctive feature (an X among Ts) gave rise to an efficient, pop-out search, evidenced by a flat slope in all first order measures (RTs, Error rates and IES) with increasing set-sizes. In contrast, the search for a conjunction of the same two features (an L among Ts) yielded inefficient searches: an increased number of distractors decreased performance. Thus, our conjunction search stimuli did create capacity limitation which is not present in feature search.

Results on the introspection of the number of scanned items do not parallel the objective, first order results. Our prediction was a flat slope for FS as a function of set-size and a steeper SNSI slope for CS. We found that the number of items scanned increased in both search conditions as a function of set-size, without significant differences between them. The absence of any reported subjective difference between the two searches forces us to conclude that participant have no introspective access to capacity limitation.

Furthermore, as demonstrated by the results on the iRT and confidence scales, our participants were able to report well-established second order parameters: Confidence correctly tracks task difficulty, and iRT follows objective RT. Both subjective measures reveal introspective knowledge of the general structure of the experimental control, indicating that, after the decision has been made, participants are aware of some general properties of their decision processes.

The pattern of results we find runs directly counter to what previous quantified introspection paradigms would lead us to predict. Indeed, results using the Psychological Refractory Period paradigms (Corallo et al., 2008; Marti et al., 2010) pointed to a greater subjective availability of central decision processes as opposed to perceptual stages in an elementary cognitive task. Here, we found the opposite: the set-size factor which is the more perceptual of the two, gives rises to differentiated introspection, whereas search type, which is more central, as it directly modifies the nature of the decision process, does not. Notice that in a sense this null result, ironically, is a good defense against the charge that high level introspective questions should not be used, because reports will be tainted by confabulations (Nisbett & Wilson, 1977). While the stimuli were easily differentiated retrospectively and their impact on the difficulty of the decisions was accessed through confidence and subjective duration of the search, participants did not confabulate.

The increase in SNSI with set-size may indicate that participants maintain a fixed width attentional window, irrespective of guidance (Wolfe, 1994, 2007). By necessity, such a window would encompass more items as set-size increases (Young & Hulleman, 2012), because the imaginary circle on which our stimuli are positioned has a fixed radius. According to this hypothesis, SNSI indexes the quantity of information recovered in parallel during the first pre-attentional stage of the search, but would not selectively distinguish the type of attentional control specific to each type of search.

If one takes into account both the effect of set-size on SNSI and the results on the confidence and iRT scales, our results are in overall agreement with Nisbett and Wilson: on a trial-by-trial basis, participants are introspectively aware of the perceptual load of the stimulus; they are also introspectively aware of some state consequences of the cognitive processes involved (confidence and self-observed global response duration); but they are mainly unaware of the processes themselves. However, this interpretation is open to methodological objections, as it rests on a null result. This could be the consequence of a deficiency at any of the following levels: (i) the cognitive difference targeted might not exist; (ii) introspection might not be able to access it; (iii), the means we give our participants to report their introspection might be inadequate.

This third possibility seems ruled out by the fact that there is a significant impact of set-size. However, before we can proceed any further, we first need to address the first objection, namely that we did not find any introspective difference between the two search types because they did not generate different processes: Both might be equally guided and capacity limited. Thus, we need independent empirical evidence of differential capacity limitations in our two search conditions, in the context of our stimuli and tasks. We designed the next experiment to address this issue.

3. Experiment 2

In the second experiment, we re-assess whether our stimuli generate distinct search processes, so that it may make sense to look for our participants' ability to gain introspective knowledge of them. We appealed to the following *objective* method: we introduced trials with two identical targets and participants had to report whether there were 1 or 2 targets. We reasoned that if capacity limits in CS are to be accessible in an introspective task, they should at least generate a bottleneck, and thus impair objective detection of an extra target. As opposed to that, in FS, the difference between one and two targets trials might be present right from the first sensory stage (Wolfe, 2003, 2007), and therefore it should be correctly detected. Additionally, if FS are done in a non-capacity limited mode, performance should be independent from set-size and from the number of targets, while this would not be the case in CS. Failure in any of these predictions would suggest that the absence of introspection we found in Experiment 1 is a faithful introspection of an absence.

3.1. Materials and methods

3.1.1. Participants

Seventeen normal adults, French speakers (12 women), aged between 20 and 32 (mean age: 23.8 years, *SD*: 3.1) participated in the study.

3.1.2. Stimuli and procedure

Visual properties of the stimuli did not differ from those in Experiment 1. With respect to the procedure, in half of the trials one or two identical targets could be presented («L», «L L», «X» or «X X», equal proportions), for the other half only distractors were presented («Ts»). When two targets were presented, both were randomly positioned on the stimuli imaginary circle, with at least one distractor between these when the set-size was higher than 2. Set-size, fixation and stimulus durations were identical to those of Experiment 1. Participants were asked about the presence or absence of at least one target («X» or «L»). Then, on 70% of the target present trials, participants were instructed to estimate the number of targets in the scene (or Identification of the Number of Targets, INT). Participants used the "U", "I" and "O" keys with the index, middle and ring fingers of the right hand to report 0, 1 and 2 targets. The experiment consisted of 10 blocks of 80 trials with a 60 s pause between each block, totaling 400 target present trials, and among them 280 trials with a forced choice estimate of the number of targets. A similar training to the one of Experiment 1 was administered before the main experimental blocks.

3.2. Results

As in the previous experiment, median RTs and mean error rate presented a positive and significant correlation across target present trials ($r^2(271) = .05$, $\beta = .24$, $t = 3.98$, $p < .001$), therefore, they were transformed into inverse efficiency scores (IES). Before this transformation, we excluded trials with response times below 200 ms and trials with response times 3 *SD* above the median (2.4%) and RTs were log-transformed to approximate normal distribution.

On the detection response, we found a pattern similar to the one of Experiment 1. Namely, search efficiency decreased as a function of set-size in CS but not in FS (see Fig. 4A). However, this interaction seemed modulated by the number of targets presented, to the effect that search efficiency for difficult target was less impacted by the set-size when there were two targets. To assess this pattern statistically, we ran an LMM on IES with fixed factors of set-size, number of targets and search type, as well as all possible interactions between these. We tested this model on target present trials. The triple interaction was significant ($F(1,248) = 6.27$, $p < .05$). We also found that the interactions between set-size and search type were significant with one and two targets (one target: $F(1,116) = 18.45$, $p < .001$; two targets: $F(1,116) = 5.96$, $p < .05$). Furthermore, with one as well as two targets, we found a non-significant slope in the FS search condition (one target: $p > .64$; two targets: $p > .92$), while it was significantly positive in the CS condition with one target ($F(1,17.5) = 7.00$, $\beta = 1.19$, $p < .05$) and marginally significant with two targets ($F(1,25.5) = 3.42$, $\beta = .37$, $p = .07$). Finally, we found a main effect of the number of targets in the CS condition so that performance was higher with two targets than with one ($F(1,118) = 11.11$, $p < .001$). In contrast the number of targets had no impact on performance in FS ($p > .10$). In sum, the number of targets facilitated search in the CS condition, but not in the FS condition.

Regarding the number of targets identification (INT), the pattern of results (see Fig. 4B) exhibited a triple interaction to the effect that, in the one target condition, increased set-size lead to reports of illusory targets in both conditions, while in the two targets conditions, we observed a sharp opposition of search types: in FS participants did report seeing both targets, but not in CS.

When we applied a LMM on correct trials with mean INT as dependent variable, we found that the triple interaction between the number of targets, the search type and the set-size factors was significant ($F(1,214.3) = 3.65$, $p < .05$). In one target trials, we only found a main effect of set-size ($F(1,25.8) = 11.90$, $p < .01$), corresponding to the illusory increase of perceived targets, without a significant difference between the search types ($p > .35$), and no interaction ($p > .85$). In contrast, in two target trials, we found a significant main effect of search type ($F(1,94.2) = 17.52$, $p < .001$), and no effect of the set-size factor ($p > .31$). The interaction was also significant, ($F(1,94.2) = 9.61$, $p < .01$): in the CS condition, the number of reported targets decreased with set-size ($F(1,77.8) = 8.43$, $\beta = -.02$, $p < .01$), while the slope was not significant in FS ($p > .88$).

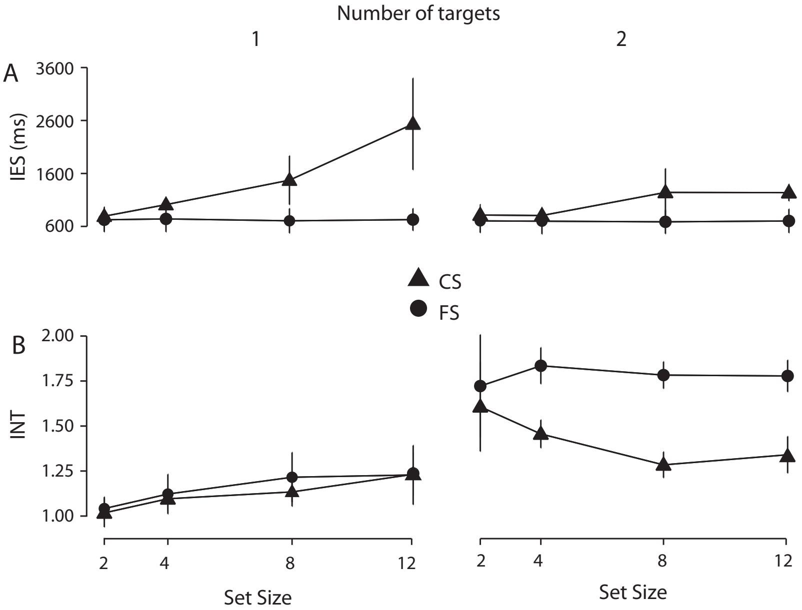

Fig. 4. (A) Inverse efficiency scores (IES) and (B) Identification of the Number of Targets (INT) as a function of set-size, and for each number of targets and search condition, in Experiment 2.

3.3. Discussion

We confirmed that our FS induces an efficient search process, while our CS induces an inefficient process. Search is so efficient in FS that a second target does not improve performance, while it does in the inefficient CS condition.

Our main interest was in the secondary task, which was a 3 alternative forced choice decision on the number of targets perceived. The logic of the two targets trials was that if search in CS is capacity limited, then participants should miss more second targets in CS, as an optimal strategy should be to stop the search as soon as they have detected the first one. Results clearly confirmed this prediction: while IES considerably improved with a second target in CS, participants missed the second target in this condition, and did so increasingly as set-size increased. One plausible interpretation is that performance with 2 targets improves in CS because the probability of identifying the first target on the scene increases, thus, the visibility of a second target decreases.

The illusory increase of perceived targets with set-size when only one target is presented mirrors the increase of SNSI with set-size in the first experiment. Set-size might be a variable that is accessed very early in the search process. With increasing set-sizes perceptual uncertainty on individual items will increase. Thus, identification of individual items might depend more on expectations (de Gardelle, Sackur, & Kouider, 2009). This would translate, in this Experiment into the increase of hallucinated second targets, and in Experiment 1, into the introspective increase in perceptual load.

In conclusion, Experiment 2 shows that our tasks generate capacity limits to which behavioral measures are sensitive. Thus, the question of whether these limits are analogously accessible to introspection is meaningful.

We now discuss the possibility that the lack of introspection for capacity limitations that we found in Experiment 1, should be specific to the implementation of the task. One aspect that might have had a decisive impact on our participants' subjective reports is the short presentation time (200 ms). Indeed, Bergen and Julesz (1983) suggest that a short presentation time favors feature searches. Time pressure in Experiment 1 may have created a bias on the first stages of the visual search process, *before* attentional guidance could comes into play. Current integrated models of visual search (Wolfe, 2003, 2007; Wolfe & Horowitz, 2004) distinguish a pre-attentional stage during which a target-like signal is extracted in parallel over the scene, and a second stage of target selection, during which attention is guided, according to the signal extracted during the first stage. In fast searches, an optimal strategy, minimizing time spent in the experiment while maintaining high performance, would be to respond quickly, on the basis of the signal extracted during the first stage. This would explain both the impact of the perceptual load in introspection and the absence of introspection of capacity limitations, as the favored strategy would be biased towards the perceptual parallel stage.

We reasoned that in order to render capacity limitation accessible, we needed to allow more time for the search and to force completion of the search. Participants should be forced not only to decide on the target presence, something they can do on average with some reliability on the basis of the information extracted during the first stage. Participants should be required to identify the target, something they cannot do until it has been put under attentional focus. To this end, we required that participants report a feature of the target orthogonal to its defining feature.

4. Experiment 3

In this experiment, we tested whether more favorable conditions would enable participants to introspect on capacity limitations. Compared to Experiment 1, we introduced the following modifications: 1 – the first order task was to report the target's color in an array of randomly colored items; 2 – the stimulus array was presented until participants responded, so as to discourage fast guesses based on incomplete processing; 3 – we added categories on top of the continuous quantitative SNSI scale, a procedure inspired by the Perceptual Awareness Scale (RamsØy & Overgaard, 2004).

4.1. Materials and methods

4.1.1. Participants

Twenty-one normal adults, French speakers (18 women), aged between 19 and 28 (mean age: 21.3 years, *SD*: 2.1) participated in the study.

4.1.2. Stimuli and procedure

The stimuli (see Fig. 5) consisted of a set of red (luminance: 58.4 cd/m^2) and green letters (luminance: 50.1 cd/m^2) presented on an imaginary circle around a central fixation (radius: 6.2°). All the trials presented targets ("X" or "L"). Set-size (4, 8 or 16 items) and the target and distractors ("Ts") orientation (0°, 90°, 180°, 270°) were randomized across trials. Stimuli were equally spaced on the imaginary circle.

Participants were instructed to decide whether the target presented was red ("Z" key) or green ("A" key). Stimuli were presented until participants responded. The SNSI scale was presented immediately after response. Under the scale four qualitative categories were specified (in French): "no item", "some items", "many items" and "all items". Each participant performed 480 trials (8 blocks of 60 trials) with a 60 s pause between blocks. A training phase similar to the one of Experiment 1 was included. Participants were instructed to avoid fast or automatic responses, and they were told that the categories on the scale were to be used as anchors for their subjective estimations, but that they should use all positions on the scale to report their best subjective estimate.

4.2. Results

4.2.1. First order task

We excluded trials with response times below 200 ms and trials with response times 3 *SD* above the median (4%). Given the low (3.8%) percentage of errors in this experiment we restricted our analyses to correct trials.

As in Experiment 1, we observed the expected interaction, reflecting the opposition of the capacity limited searches for CS and non-capacity limited for FS (see Fig. 6A). Indeed, an LMM on median correct RTs (log-transformed) revealed a significant main effect for search type ($F(1,88.7) = 269.6$, $p < .001$) and set-size ($F(1,124.2) = 95.2$, $p < .001$), and a significant interaction between these factors ($F(1,88.7) = 69.71$, $p < .001$). The CS condition lead to a significant increase in response time as a function of set-size ($F(1,41.0) = 307.6$, $\beta = .03$, $p < .001$), and a marginal one in the FS condition ($F(1,20.2) = 5.71$, $\beta = .004$, $p = .051$).

4.2.2. Second order task

SNSI responses parallel response times (see Fig. 6B). A similar LMM performed on mean SNSI revealed a significant main effect of search type ($F(1,99.9) = 125.5$, $p < .001$) and set-size ($F(1,115.0) = 33.03$, $p < .001$). The interaction between these factors was also significant ($F(1,99.9) = 22.63$, $p < .001$). Critically, set-size significantly impacted participants SNSI in CS ($F(1,20.0) = 92.98$, $\beta = .08$, $p < .001$), but not in FS ($p > .31$).

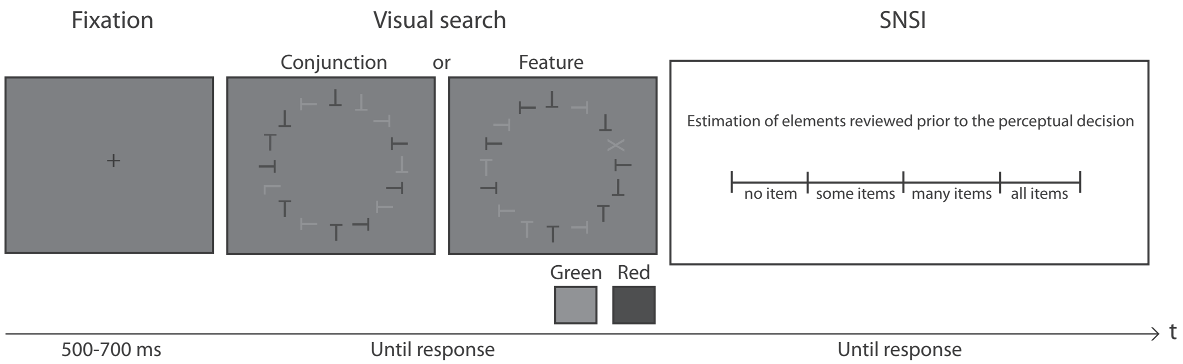

Fig. 5. General structure of the task in Experiment 3. After presentation of the fixation cross, participants had to identify, without time pressure, the color (red or green) of the target. All the trials contained one target, either an X or an L. Immediately after the perceptual decision, participants were requested to estimate the number of items scanned on a qualitatively labeled scale (SNSI). Here, red and green are represented as black and light gray.

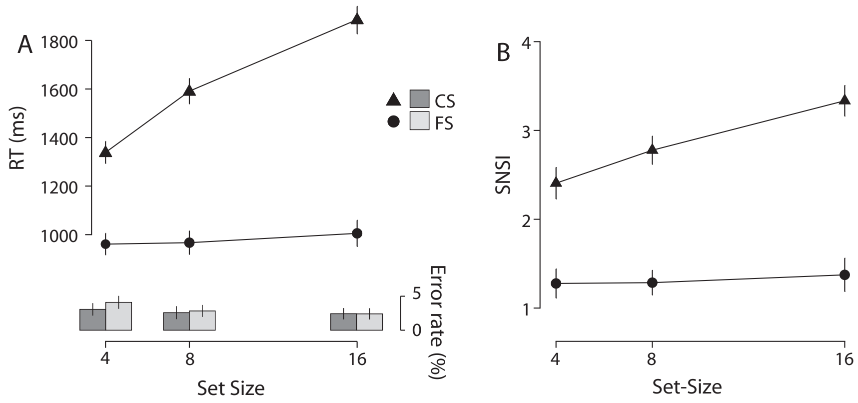

Fig. 6. Results of Experiment 3 (A) Response times and Error rates as a function of set-size in both search conditions. (B) SNSI as a function of the same search conditions.

Contrary to what we had found in Experiment 1, here, participants were able to introspect on the difference in search process generated by the FS and CS stimuli, as SNSI results parallel first order results. If we interpret first-order results as evidence for capacity limitations in CS, it seems that participants are subjectively aware of such limitations. However, these results may very well derive from inferences based on non-introspective sources of information. As discussed in the Introduction, participants might have modulated, on a trial-by-trial basis, their introspective estimation on the basis of their RTs, producing confabulatory introspective reports. To assess to what extent SNSI was contaminated by self-observation of response times, we used mediation analyses (Bauer et al., 2006). The strategy consists in testing whether the impact of search type and set-size on SNSI disappears when RTs are controlled. We focus our analysis on the interaction term between search type and set-size, given that this effect is diagnostic of capacity limitations. Disappearance of this effect would suggest that introspected capacity limitation is in fact due to self-observation of RT. Along these lines, we estimated the *total effect* (the impact of the interaction term on SNSI), the *indirect effect* (the size of the interaction effect explained by RT, i.e., the mediator variable) and the *direct effect* (the difference between the total and indirect effect, which denotes the impact of the independent variables on SNSI not mediated by changes in RT). As in previous analyses, we considered that all these effects can vary randomly between participants. Our mediation model has thus two levels: both the outcome (SNSI), the predictor (interaction between set-size and search type) as well as the potentially mediating variable (RT) constitute the first level, which are nested within each participant (i.e., second level). To test the significance of the indirect effect, we used a Monte Carlo confidence interval method (Preacher & Selig, 2012; Selig & Preacher, 2008). We refer the reader to the Appendix for the details of the model.

In agreement with the previous analysis, we found a significant *total effect* of the interaction term on SNSI ($F(1,19.9) = 194.0$, $c = .02$, $p < .001$). We also found that the interaction term impacted RTs ($F(1,19.8) = 489.5$, $\alpha = .04$, $p < .001$). In addition, controlling the interaction effect on SNSI, RT presented a significant relationship with SNSI ($F(1,20.1) = 171.3$, $\beta = .29$, $p < .001$), which is required for RTs to be considered as potential mediator. Finally, after controlling the RT effect on SNSI, we found that the impact of the interaction on SNSI was reduced (*direct effect*: $F(1,19.9) = 39.34$, $c' = .007$, $p < .001$). Thus, we found a partial mediation of SNSI by RTs: the size of the *indirect effect* was .013 (C.I. [.011, .016]). In other terms, 65% of the effect of the interaction term on SNSI was mediated by RTs.

4.3. Discussion

In this experiment, we again observed the contrast between feature searches (FS) and conjunction searches (CS): increasing set-sizes gave rise to a significantly steeper RT slope in CS than in FS. Errors were not informative, which is a consequence of the search array being presented until participants' responses. Results on the SNSI scale suggest that participants' introspection not only showed a global difference between the search conditions, but also and importantly, SNSI increased as a function of the number of distractors in the array only in CS. Furthermore, the impact of the interaction between set-size and search type on the subjective number of scanned items was only partially mediated by response times. Thus, capacity limits are, at least in part, introspectively accessible by pure mental monitoring, provided that the context of the task makes them sufficiently salient.

Even though the introspective task was identical in Experiments 1 and 3, the context influenced how it was performed: in Experiment 1, high speed demands favored introspection based on the first perceptual stage, and we found only an effect of perceptual load in introspection. Here, the demands of the task shifted towards the second, target identification stage, and participants' introspection followed suit. We suggest that when task contexts vary, introspection flexibly adapts to different aspects of the same cognitive processes.

Our mediation analyses showed that response times have a major impact on introspection. We can speculate on how this comes about: first, it may happen through a contaminating bias, i.e., introspective response times were automatically computed, in parallel with the pure SNSI, and then biased responses. Second, response times may impact the estimates on the SNSI scale through confabulation, i.e., if participants have a theory about the link between response duration and the number of scanned items during the decision process. Third, there might be a real introspective process link: without any explicit theory, participants' spontaneous introspective task setting might use diverse sources of information, including decision duration and self-observation of response times.

In the next experiments, in order to control and possibly factor out the use of self-observation in introspection, we used a fixed stimulus presentation time and a late response window (Experiment 4a and 4b), and we recorded (Experiment 4a) or controlled (Experiment 4b) eye movements.

5. Experiments 4a and 4b

In these experiments we seek to better understand the nature of the information used by participants' introspection. For this purpose, we kept the same first-order stimuli and second order task as in Experiment 3. We only introduced a fixed stimulus duration and a response window: responses could only be produced during a 1000 ms response window that began immediately after a fixed 3000 ms stimulus presentation. In addition, we recorded gaze position during stimulus presentation so as to include eye movements as possible mediators in the analysis of introspective responses. The only difference between Experiment 4a and 4b, was that in the former eye movements were allowed but not in the latter.

5.1. Materials and methods

5.1.1. Participants, stimuli and procedure

In Experiment 4a, eighteen normal adults, French speakers (9 women), aged between 18 and 28 (mean age: 22.8 years, *SD*: 2.7) participated. Each participant performed 288 trials (8 blocks of 36 trials) with a 60 s pause between blocks. A similar training to the one of Experiment 1 was administered before the main experimental blocks. Eye movements were recorded monocularly with an eye tracker (EyeLink 1000 system, SR Research, Canada), with a sampling rate of 1000 Hz and a spatial accuracy better than 1° (camera-eye distance: ~55 cm). Saccades were determined using a conservative algorithm (velocity threshold: 30°/s, acceleration threshold: 8000°/s^2, motion threshold: 0.15°). For all participants the right eye was recorded. Stimuli were identical to those of Experiment 3, except that their duration was fixed at 3000 ms. Participants could only respond during a 1000 ms window beginning at stimulus offset. A recalibration procedure for the eye tracker was conducted before each block.

In Experiment 4b, fifteen normal adults, French speakers (11 women), aged between 19 and 29 (mean age: 22.7 years, *SD*: 2.5) participated. The stimuli and procedure did not differ from those of Experiment 4a, except that in this study, participants were requested to fixate on the cross at the center of the stimuli during the entire 3000 ms presentation time. An invisible circle (radius: 3.0°) around fixation determined the degrees of freedom of eye movements: participants were told that if their gaze moved away from the fixation cross, the trial would be considered incorrect, and the next trial would begin immediately. During the training period, participants were trained to suppress eye movements during the presentation of the stimuli.

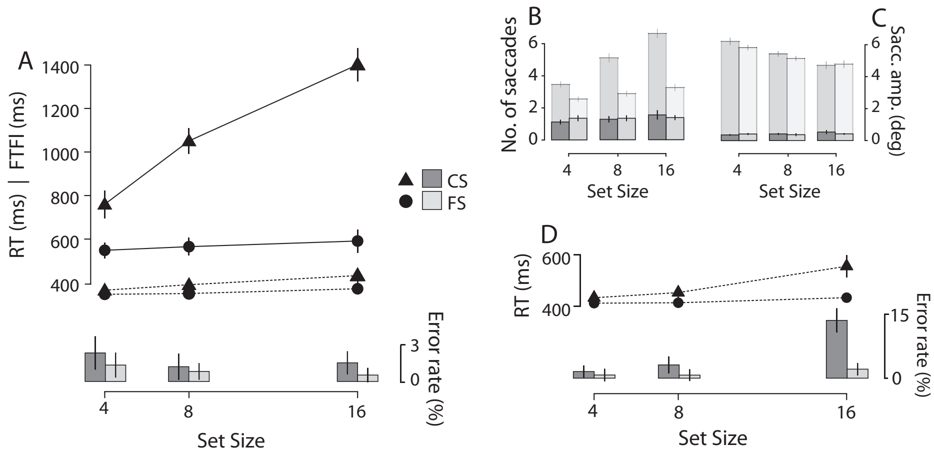

Fig. 7. (A) Plain lines indicate First Target Fixation Latency (FTFL) and Error rate as a function of both search conditions. Dashed lines indicate RT as a function of the same conditions, in Experiment 4a. (B) Number of saccades and (C) saccade amplitude as a function of the same conditions, in Experiment 4a (light gray bars behind each graph) and in Experiment 4b (solid gray bars). (D) RT and Error rate as a function of set-size in both search conditions, in Experiment 4b.

5.2. Results

5.2.1. Experiment 4a: First order task

Given the low percentage of errors in this experiment (2%), they were not analyzed. Although the response window greatly sped-up motor responses (see Fig. 7A, dashed lines), they still showed a pattern analogous to the one of Experiment 3. An LMM was run on median log-transformed RTs. All main effects and the interaction were significant (search type: $F(1,69.8) = 15.59$, $p < .001$; set-size: $F(1,17.2) = 33.56$, $p < .001$; interaction $F(1,69.8) = 14.88$, $p < .001$). As in Experiment 3, we found a significant and steeper slope for CS ($F(1,17.7) = 38.40$, $\beta = .013$, $p < .001$) than for FS ($F(1,17.3) = 10.28$, $\beta = .005$, $p < .01$).

Next, we analyzed the latency of the first fixation on the target (First Target Fixation Latency, FTFL). We defined a square window around the target (0.8° × 0.8°), and measured the latency with respect to the first fixation of at least 50 ms within this window. As shown in Fig. 7A, the latency of the first fixation on the target mirrors the interaction pattern previously found on response times. We ran an LMM on median FTFL (log-transformed) within correct trials. Again, the main effects and the interaction were significant (search type: $F(1,75.4) = 103.7$, $p < .001$; set size factor: $F(1,24.0) = 131.8$, $p < .001$; interaction: $F(1,75.4) = 44.22$, $p < .001$). The CS condition showed a steeper slope as a function of set-size ($F(1,28.1) = 115.8$, $\beta = .05$, $p < .001$) than for FS ($F(1,19.2) = 31.88$, $\beta = .01$, $p < .001$). In addition, as shown in Fig. 7B (light gray bars), the number of saccades (log-transformed) follows a similar patter; the two main effects and the interaction term were significant (search type: $F(1,72.3) = 56.63$, $p < .001$; set-size: $F(1,13.8) = 114.9$, $p < .001$; interaction: $F(1,72.3) = 23.27$, $p < .001$; CS: $F(1,35.0) = 135.3$, $\beta = .05$, $p < .001$; FS: $F(1,35.0) = 23.45$, $\beta = .02$, $p < .001$). Finally, we also analyzed mean saccade amplitudes (log-transformed), during the same time window, with a similar LMM. We observed again that the two main effects and the interaction term were significant (search type: $F(1,67.8) = 10.14$, $p < .01$; set-size: $F(1,20.8) = 109.8$, $p < .001$; interaction: $F(1,67.8) = 4.00$, $p = .051$). A more detailed examination indicated that both in CS ($F(1,22.2) = 116.5$, $\beta = -.02$, $p < .001$), as well as in FS ($F(1,35.0) = 39.71$, $\beta = -.01$, $p < .001$), the saccade amplitude decreases as a function of set-size (see light gray bars in Fig. 7C). This decrease may be due to the fact that the radius of the imaginary circle for stimuli is constant. Consequently, with small set-sizes, participants' search will involve greater amplitude eye movements, because stimuli are farther apart.

5.2.2. Experiment 4b: First order task

One participant was excluded from the analyses because he had unusually high error rates (>50%). In this experiment 8% of the trials were excluded from the analysis because eye movements exceeded the acceptable fixation zone.

As previously, RTs exhibited the typical visual search interaction (see Fig. 7D) and this was confirmed by an LMM on median correct (log-transformed) RTs (set-size: $F(1,14.5) = 29.35$, $p < .001$; search type: $p > .25$; interaction $F(1,57.6) = 24.99$, $p < .001$). We also found a significant increase of RTs as a function of set-size in CS ($F(1,14.5) = 28.64$, $\beta = .02$, $p < .001$), but not in FS ($p > .10$). In the similar LMM on error rate (arcsine transformed) we found the same significant effects (set-size: $F(1,24.0) = 24.24$, $p < .001$; search type: $p > .64$; interaction: $F(1,72.0) = 33.34$, $p < .001$), which was characterized by a higher increase in CS ($F(1,18.3) = 24.66$, $\beta = .01$, $p < .001$) than for FS ($F(1,18.2) = 5.88$, $\beta = .001$, $p = .05$).

As expected, the instruction to fixate introduced a drastic change in eye movements (see Fig. 7B and C). No significant effects of the experimental variables were found on the number of saccades nor on the saccade amplitude (all $ps > .10$).

5.2.3. Experiment 4a: Second order task

As shown in Fig. 8, participants' introspection depended on the two factors of set-size and search type. In an LMM performed on mean SNSI, we found that both main effects, as well as the interaction were significant (search type:

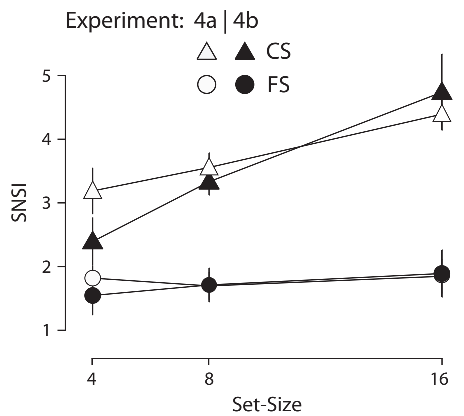

Fig. 8. SNSI as a function of set-size in both search conditions in Experiment 4a (empty symbols) and in Experiment 4b (filled symbols).

$F(1,70.0) = 89.17$, $p < .001$; set-size: $F(1.17.0) = 21.13$, $p < .001$; interaction: $F(1,70.0) = 22.54$, $p < .001$). A more detailed look at the interaction revealed that SNSI increased as a function of set-size in CS ($F(1,35.0) = 53.92$, $\beta = .10$, $p < .001$), but not in FS ($p > .60$).

Then, we investigated the possible contamination of this interaction effect by self-observation. First, we ran a multilevel mediation model with RTs as mediator. The analysis showed a significant interaction between set-size and search type on SNSI ($F(1,16.9) = 260.5$, $c = .06$, $p < .001$) and on RTs ($F(1,17.3) = 128.3$, $\alpha = .01$, $p < .001$). Second, controlling the interaction effect on SNSI, we found a significant impact of RTs on SNSI ($F(1,13.8) = 54.35$, $\beta = .32$, $p < .001$). Finally, when the impact of RTs on SNSI was controlled, the interaction effect was marginally reduced ($F(1,381.4) = 520.7$, $c' = .05$, $p < .001$, indirect effect: .005, C.I. [.003, .006]; 8% contaminated). Following this logic, we found that the interaction between set-size and search type had a significant impact on first target fixation latency (FTFL) ($F(1,17.3) = 387.3$, $\alpha = .06$, $p < .001$). At the same time, FTFL presented a significant relationship with SNSI, after controlling the interaction term ($F(1,17.1) = 85.89$, $\beta = .67$, $p < .001$). Then, after controlling FTFL, we observed that the interaction impact on SNSI was only partially mediated by the latency of the first fixation on the target ($F(1,379.9) = 127.6$, $c' = .01$, $p < .001$, indirect effect: .04, C.I. [.037, .045]; 66% contaminated).

Moreover, we found a significant interaction effect between set-size and search type on the number of saccades ($F(1,17.1) = 542.5$, $\alpha = .06$, $p < .001$), a significant impact of the number of saccades on SNSI, after controlling the interaction term ($F(1,17.2) = 93.26$, $\beta = .17$, $p < .001$) and a significant interaction effect on SNSI, after controlling the number of saccades effect on SNSI ($F(1,17.8) = 35.01$, $c' = .05$, $p < .001$). These results suggest a marginal mediation effect of the number of saccades (indirect effect: .01, C.I. [.009, .014]; 16% contaminated). Finally, we found a significant interaction effect between set-size and search type on the saccades amplitude ($F(1,16.6) = 37.91$, $\alpha = -.01$, $p < .001$). Then, after controlling this effect, we observed a significant impact of the saccades amplitude on SNSI ($F(1,17.8) = 55.40$, $\beta = .16$, $p < .001$) and a significant interaction effect on SNSI, after controlling the mediator ($F(1,16.4) = 261.5$, $c' = .06$, $p < .001$). However, the indirect effect was not significant: −.002, C.I. [−.008, .008]).

5.2.4. Experiment 4b: Second order task

Participants' introspection presented the same pattern as in the previous experiment. A similar LMM on mean SNSI showed that both main effects, as well as the interaction, were significant (search type: $F(1,55.3) = 18.05$, $p < .001$; set-size: $F(1,14.8) = 33.19$, $p < .001$; interaction: $F(1,55.3) = 32.81$, $p < .001$). This interaction was characterized by a significant SNSI increase as a function of set-size in CS ($F(1,14.2) = 47.21$, $\beta = .19$, $p < .001$), but not in FS ($p > .10$, see Fig. 8). Then, we evaluated whether this interaction effect was mediated by RTs or eye-movements, even though both were restricted in this experiment. Multilevel mediation models showed that the interaction between set-size and search type presented a significant effect on SNSI ($F(1,13.2) = 67.74$, $c = .03$, $p < .001$) and on RT ($F(1,15.0) = 49.72$, $\alpha = .01$, $p < .001$). After controlling the interaction effect, we found a significant RT/SNSI relationship ($F(1,14.1) = 31.38$, $\beta = .10$, $p < .001$). Finally, controlling this RT effect, the interaction effect on SNSI was only marginally reduced ($F(1,13.1) = 63.24$, $c' = .03$, $p < .001$, indirect effect: .0018, C.I. [.001, .002]; 6% mediated). The same model ran on the number of saccades ($\alpha = .007$, $p > .53$) and on the saccade amplitude ($\alpha = .006$, $p > .13$), confirmed that none of these variable presented a significant relationship with the interaction term.

5.3. Discussion

In Experiment 4a, we tried to factor out response times, so as to assay whether participants could still do the introspective task without access to this behavioral information. Our use of a response window had a drastic influence on response times, without totally eliminating the information they carry about the search processes, as evidenced by the fact that we still find a pattern of response times characteristic of capacity limited and unlimited searches. Eye movement results agree with the literature: the number of saccades was higher in CS than in FS, increasing with greater intensity in CS as a function of the number of distractors in the scene. Most importantly, the latency of the first fixation on the target exhibited the same interaction pattern as response times.

Our second order measure also showed the interaction between search type and set-size factors, that we interpret as a sign of introspective access to capacity limitations. Thus, even though we managed to greatly diminish the saliency of behavioral responses with the response window, this manipulation did not drastically modify participants' subjective estimate, confirming the robustness of our results, and suggesting that introspection can diagnose differences between the search conditions. In line with this result, we found that the mediating role of response times with respect to SNSI is now greatly reduced although not absent. This suggests that self-observation of overt response behavior is not a necessary source of information for the form of introspection that we elicit from participants.

In Experiment 4b, we controlled eye movement during the first order task, because Experiment 4a demonstrated that eye movements were a potential source of self-observation as they acted as mediating variables. We hypothesized that if participants' introspection, as reported in Experiments 3 and 4a, is not solely due to eye movement, we should observe the same SNSI pattern if we controlled them. This was indeed the case. Thus, it seems that introspection is still possible when self-observation both of manual response times and eye-movements are not available.

6. General discussion

In this article, we investigated whether one could have introspective access to cognitive processes, as opposed to introspective access to the cognitive states or behavioral consequences that they generate. To do so, we used two visual searches as our test bed: a difficult, capacity limited search, and an easy, non-capacity limited search. We thus endeavored to test Nisbett and Wilson's (1977) thesis about the limits of introspection, within the context of elementary cognitive processes. We devised an introspective task such that participants had to report how many items they felt they had scanned during the search process (the Subjective Number of Scanned Items, SNSI), which we took as an index of the subjective access to capacity limitation, or an inverse index of the strength of attentional guidance.

Two broad classes of results emerge from the series of four experiments we present, and they all point to flexibility and contextual modulation of introspection. The first class of results stems from the contrast between Experiment 1 and the four other experiments. In Experiment 1, we discovered that participants' reports of SNSI were sensitive only to the overall number of items in the search array, without much hint at sensitivity to the difference between capacity limited and unlimited processes. This negative result was all the more notable than in the same experiment, the two other second order tasks we used (i.e., confidence and introspective response times) did show good metacognitive sensitivity. As opposed to this null result, in Experiments 3, 4a and 4b we found clear evidence of behavioral and introspective access to the difference in capacity limitations. The critical distinctions between the two sets of experiments were the short presentation time of stimuli in Experiment 1 (200 ms) compared to the long presentation (unlimited/3000 ms) in the others, on the one hand, and the fact that the search task demanded *identification* of the target in the last group of experiments, as opposed to simple *detection* in the first experiment, on the other hand.

The null result of Experiment 1 with respect to introspection of capacity limitation has, first, an important methodological import: it means that the SNSI task we rely on is not trivially contaminated by confabulation. It is not the case that participants report that they scanned more items when the task is more difficult, or even, when they search for an L among Ts as opposed to an X among Ts, because they rely on a theory that the former must require extensive scanning. In fact, as results on confidence ratings and subjective duration of the task showed in Experiment 1, participants clearly introspected at the trial level that capacity limited searches were more difficult and took longer to perform than capacity unlimited searches. But that did not translate into an increase of the number of items they subjectively felt they had scanned. As further experiments showed, on the contrary, that the SNSI task can be sensitive to capacity limitations, the null result of Experiment 1 must be interpreted as a sign of introspective inaccessibility. To make sure that there was indeed a genuine difference between our two searches, in other words, that the pattern of behavioral first-order results was not simply mimicking differences in capacity limitation, we used a non-introspective procedure in Experiment 2, which demonstrated that our two searches did create two qualitatively different search processes. In brief, something was available to introspection in Experiment 1, but it was not accessed.

We now interpret this result in the light of recent models of visual search (Wolfe, 1994, 2003, 2007; Wolfe et al., 2011) that distinguish two stages: a first parallel stage consisting of extraction of visual features, and a second, possibly guided, stage of target selection. We hypothesized that when the stimuli are presented for a brief duration, the search process is imbalanced in favor of the first stage; so that responses are generated mostly on the basis of the information extracted during the first parallel pass. A rational cost/benefit analysis of optimal behavior, in the sense of maximizing correct responses while minimizing time in the experimental booth, might show that in such circumstances it is best not to commit too much resources in guided target selection, as this would lengthened each decision without much benefit to performance. In this situation, the decision variable simply integrates the information available after feature extraction over the entire display. On the contrary, in the latter group of experiments, both modifications concur to shifting the optimal behavior towards slower, possibly guided searches; as the display is shown for a longer time, it is beneficial to spend more time in the search. In addition, as the task requires target identification, the cost of not finishing the search would be disproportionate.

According to this speculative hypothesis, the controversy between pure signal detection models of visual search (Cameron et al., 2004; Carrasco & McElree, 2001; Carrasco & Yeshurun, 1998) and guidance models might be more a matter of relative weighting of search subprocesses according to task context, than a question about the essence of visual search. Furthermore, we suggest that introspection tracks the imbalance of these sub-processes: when the first pass dominates, the subjective number of scanned items corresponds to the complexity of the scene. When the context of the task renders the second, selection stage critical to optimal performance, then it contributes to introspection, and participants are subjectively aware of the presence or absence of guidance in the search. This takes precedence on whatever subjective salience the complexity of the scene could have had.

Critically, what we hypothesized as an imbalance in the search processes is not marked in the pattern of response times which, in each and every of our 4 experiments, exhibited the traditional interaction of set size and search type factors. However, we suggest that this surface similarity across the first and latter experiments hides processing differences that introspection is able to reveal. The notion of "model mimicking", familiar from the literature on serial *versus* parallel processes (Townsend & Wenger, 2004), is precisely meant to capture the fact that this interaction, which could easily be taken as diagnostic of the opposition of limited and unlimited processes, is in fact a *non-sequitur*. Here we argue that in our Experiment 3 the interaction is indeed a sign of the opposition of two types of processes, whereas in Experiment 1 it is not. We base this conclusion on the absence of any introspective difference between the search processes in Experiment 1, as opposed to clear differences in the last experiments.

If the above reasoning is correct, the increase in SNSI reports with set-size in Experiment 1 corresponds to the increasing perceptual load, caused by information accrual during the first stage of feature extraction, while in the latter experiments it corresponds to an introspective access to capacity limitation. Of course, this interpretation raises the difficulty that the very same instruction to introspect is in fact ambiguous and corresponds to different internal targets for introspection. Indeed, we did not change the wording of the instruction for the SNSI across experiments. However, we should note here that this ambivalence of instructions with respect to introspection is in fact not an accident but an essential feature of introspection (Jack & Roepstorff, 2002), as there is by definition no external fact of the matter to which performance can be aligned. Moreover, our study demonstrates that this ambivalence can be tamed, so that introspective data can be used both, on the one hand, with a view to complementing basic behavioral responses in order to better understand cognitive processes, and on the other hand, in order to understand the process of introspection itself.

The second class of results concerns the purity of the introspective judgments. In Experiments 4a and 4b, we successfully isolated reports on the number of internally scanned items from two major potential contaminants, namely response times and eye movements. We showed, using both experimental controls and statistical analyses, that introspection on the target selection stage is not a construction based on other informational sources that are already known to be accessible to self-observation, e.g., response times (Corallo et al., 2008; Marti et al., 2010).

It seems that we succeeded in eliciting pure mental process monitoring from our participants. Miller et al. (2010) used a simple go/no-go tasks to probe pure mental monitoring of decision time, and concluded that "decision time reports are not very accurate but they may be usable for some purposes". To reach this conclusion they relied on manipulations of difficulty in the primary task, which is supposed to influence internal decision time, and on manipulations of the complexity of the response, which by contrast is not supposed to impact decision time. However, note that the authors did not use a direct manipulation of the response time itself. Therefore, the purity of the subjective decision time reports is not beyond doubt, and reports may well be in part contaminated by self-observation of behavior. By contrast, we made sure that introspection of the cognitive processes in visual search derives from direct access to them, and does not build on inferences based on overt or covert behavior. The SNSI task is thus, to our knowledge one of the first clear instance of pure mental monitoring, as opposed to behavioral self-observation. Of course we must be cautious with respect to the selectivity of our introspective measure: rather than reporting the number of scanned items, participants may have reported their internal decision time. These two variables are of course highly correlated, and it is difficult to decide between them, as the only diagnostic feature might be whether the distribution of responses is discrete or continuous. Be that as it may, both cases are clear cases of pure mental monitoring, the possibility of which was the main question of our study.

Thus, contrary to the claims of Nisbett and Wilson (1977), we should state that introspection of mental processes, and not only of mental states, is possible. Of course, we should keep in mind the very specific conditions under which this is true:

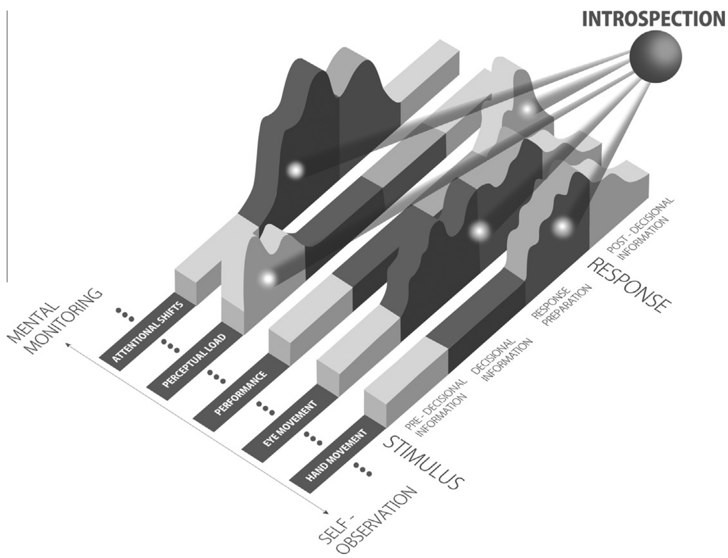

Fig. 9. Schematic representation of the flexibility of introspection. The model represents the flexibility of introspection in two dimensions. The first dimension (mental monitoring – self observation) organizes sources of information on which introspection is focused. When an introspective index primarily uses behavioral information sources, introspection is conceptualized as a process of self-observation. By contrast, when the introspective source of information comes from the cognitive processes, the index is properly conceptualized as mental monitoring. The second dimension (early *versus* late sub-processes) specifies different stages, during the development of the first order task, at which mental states are available to introspection.

First, the first order task that is the target of introspection is elementary and short. Our results may not extend to more complex and longer tasks, where the latitude for confabulations may be higher. However, the results on the rehearsal literature (Kroll, Kellicutt, & Parks, 1975; Montague, Hillix, Kiess, & Harris, 1970) suggest that in some cases introspection could be reliable at longer time scales than ours. Second, we designed the first order task so as to maximize the salience of the attentional guidance in the target selection stage of our visual search. Third, introspection was performed systematically and immediately after the first order task, so that participants were trained to focus on the processes of interest, and could report their introspection while it was still present in working memory. It is notable that all these conditions correspond to the recommendations of previous and contemporary researchers on introspection (Schooler, 2002; Titchener, 1899).

We can tentatively synthesize our results in a descriptive model of introspection (see Fig. 9). In this model we represent two dimensions that define the space within which introspection can flexibly be focused: first, the dimension that opposes mental monitoring and self-observation, and second the timing with respect to task processes. Previous results (Corallo et al., 2008; Marti et al., 2010) and the present ones suggest that participants can focus their introspection on data that are more or less objective. We suggest that there is a gradation with respect to the purity of introspection, with pure mental monitoring at one extreme and pure self-observation at the other. On the other dimension, we suggest that participants are able to introspectively focus on different stages of a given task process. This is evidence in our study by the contrast between Experiment 1 and the last two. We must also mention here the literature on error monitoring (Yeung & Summerfield, 2012) that opposes conflict monitoring (van Veen & Carter, 2002; Yeung, Botvinick, & Cohen, 2004) and post-decision processing (Petrusic & Baranski, 2003; Resulaj, Kiani, Wolpert, & Shadlen, 2009) as potential sources of error detection. This opposition can also be understood in terms of whether introspection is focused on early or late task processes.

This model can serve as a framework for further research on the mechanisms of introspection: if it is true that introspection can flexibly move within this task processes space, it is not self-evident that it could be divided, so that different portion of this space could be simultaneously monitored.

These questions are critical with respect to the possibility of compound introspective tasks, an issue which is particularly important with respect to confidence. The bases of confidence judgments, which one may think as the most important introspective task, from a behavioral perspective, are so far unclear. Indeed, recent models of confidence (e.g., Pleskac & Busemeyer, 2010; Ratcliff & Starns, 2009) suppose that confidence in simple choices is driven by the rate of information accrual during the decision. Transposed within the present framework, this would mean that confidence is the resultant of mental monitoring of the speed to reach the decision. An alternative hypothesis, which admittedly is so far purely speculative, would be that confidence is a compound metacognitive judgment, which might integrate various sources accessible to introspection.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2014.08.009.

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Two dimensions of visibility revealed by multidimensional scaling of metacontrast

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An increasing number of studies use subjective reports of visibility, so as to delineate the domain of perceptual awareness. It is generally assumed that degrees of visibility can be ordered on a single unidimensional scale. Here, I put this assumption to test with metacontrast, one of the most studied visual masking paradigms. By means of multidimensional scaling, I show that even though metacontrast stimuli only differ along the dimension of time, the perceptual space they generate unfolds in three dimensions: time and two kinds of visibilities, that are confounded when projected onto a unitary visibility scale. I argue that metacontrast creates multidimensional complex percepts, a property that may run counter to its use as a simple modulator of visibility. More broadly the results cast doubt on the use of visibility scales that ignore the qualities of the percepts.

1. Introduction

The emergence of a scientific study of consciousness has been accompanied by the development of a vast array of new methods and measures. Among these methods is the use of subjective visibility scales (see for instance Sergent & Dehaene, 2004; Ramsøy & Overgaard, 2004). These measures are meant to capture participants' subjective impression of seeing. It is argued that subjective measures better correspond to conscious awareness of the stimulus than performance in a forced choice task (detection or discrimination), as is traditionally used in psychophysics, since forced choice performances can be influenced by unconscious processing. However, these methods all come with the implicit assumption that visibility can be gauged on a single ordered dimension.[1] Here, I put this assumption to test on the case of metacontrast stimuli.

Metacontrast is one of the most often used and most studied (see Breitmeyer & Öğmen (2006), for a comprehensive review) methods for masking a visual stimulus, i.e. to modulate its visibility. Metacontrast is produced when a brief stimulus (the target) is followed by a second brief stimulus (the mask) that surrounds and abuts it without overlap. When the interval between the two stimuli is below around 150 ms, the second stimulus profoundly modifies the visibility of the first stimulus, to the extent that its features may become indiscriminable, and that, in some cases (Otto, Öğmen, & Herzog, 2006) the target itself may be invisible. Since the first observations made by Stigler (1910), it has been extensively used both as a tool for the study of early vision, and as a method for the fine control of visual awareness.

However, there is more to metacontrast than visibility. In metacontrast, time, most often operationalized as the

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[1] Notice that this assumption is also implicit when visibility is computed as the mean of seen/not seen judgments as in Lau and Passingham (2006).

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Stimulus Onset Asynchrony (SOA) between the target and the mask, varies along a single dimension. Perhaps surprisingly, this unidimensional manipulation creates a host of quite different phenomena. For instance, the mask impacts both the apparent brightness of the target and its perceived contour (Breitmeyer et al., 2006), while these effects have different and distinctive timecourses – the "metacontrast functions" that relates the target/mask SOA to the measured effect. Moreover, metacontrast does not simply modify the visual features of the target, but also its position in time and space: perceived onset time of the target (Didner & Sperling, 1980) and estimates of the target's spatial position (Sigman, Sackur, Del Cul, & Dehaene, 2008) are both shifted by the mask. While all these effects show a massive backward influence of the mask on the target's percept, simple response times to the target are not affected by the mask (Fehrer & Raab, 1962; Neumann & Scharlau, 2007; Raab et al., 1961, but see Proctor, Bernstein, & Schurman, 1974) Similarly, Vorberg, Mattler, Heinecke, Schmidt, and Schwarzbach (2003) found that the timecourse of the motor priming effect of a target was unrelated to whether it was masked or not by metacontrast, suggesting again that metacontrast selectively modulate some aspects of target processing while sparing others (see also Kunde, 2003, who extends the dissociation at the level of control mechanisms).

Interestingly, the effect of metacontrast is quite often a non-monotonic function of the SOA: Performance on shape discrimination and ratings of the visibility of the target may start at a high value for short SOAs, then decrease at intermediate ones and rise again and plateau for long SOAs (U-shaped, "type B" metacontrast). But the U-shaped timecourses of visibility and discrimination or detection performances are not always exactly parallel. Thus one can sometimes find two SOAs across the trough of the metacontrast function such that performance is equated while visibility is lowest for the shortest SOA ("relative blindsight", Lau & Passingham, 2006; Jannati & Di Lollo, 2011). This shows how promising a tool metacontrast is for the study of visual awareness, since it may enable a measure of "pure" visibility (be it about the target's presence, or most often about the discriminability of the target's features), unadulterated from behavioral performance differences.

However, even though metacontrast is very often used as a tool for the control of visibility, one should not forget that it is a multidimensional phenomenon. As such it affords multiple "criterion contents" (Kahneman, 1968): Observers can use many different cues, on various dimensions, when asked to process a metacontrast stimulus. This might be particularly true when observers are asked to rate the visibility of the target, as visibility is a very broad construct. What it means "to see or not to see" a target when it is masked by metacontrast can have many different meanings for different observers in different conditions. Yet, while criterion content has been recognized as potentially critical in metacontrast for a long time, it has rarely been at the top of metacontrast researchers' agenda. One reason for this situation is, as Bernstein, Fisicaro, and Fox (1976) point out, that a thorough study of criterion content seems to require that one rely on subjective verbal descriptions of experience – which Bernstein et al. (1976) eschewed by relying on discriminant function analysis.

Thus, despite its obvious multidimensional nature, most extant studies of metacontrast have relied on predefined scales to measure the effect of the mask (apparent brightness, contour discrimination, visibility of the target, etc.), thereby imposing the perceptual dimension along which the stimulus is to be assessed. This state of affairs may obscure the correspondence of the scales investigated with the subjective dimensions of metacontrast, as well as observers' ability to select some specific dimension best suited for the task at hand. As a first foray into these questions, I used Multidimensional Scaling, which is based on subjective similarity judgments, and not on complex verbal reports, in order to unfold the underlying perceptual space of metacontrast. This allows me to test whether visibility of the target is among the "natural" dimensions of metacontrast.

Multidimensional scaling (MDS, Shepard, 1980) is used to recover the overall structure of the subjective space for a class of representations, based on pair-wise similarity judgments. Subjective similarities may be thought of as distances in psychological space. In MDS, one tries to go from the matrix of all pairwise distances to the map that may have generated it, with as little distortion as possible. The percepts generated by a set of N stimuli can be represented in a $N-1$ dimensional space, without distortion, provided that similarities are *bona fide* distances. But of course, the goal of the procedure is to find some lower dimensional space, the dimensions of which we can interpret. The distortion thereby introduced (technically the "stress") is then conceived as unexplained variance. Following this logic, I devised an experiment where, on each trial, I presented observers with two metacontrast stimuli, and asked them to rate their similarity. Stimuli differed only as regards SOAs, while all other properties were identical. To compare the MDS results with more traditional measures and facilitate interpretation, in a separate experiment, I collected discrimination performances and visibility judgments. Furthermore, to assay the separability of visibility of the target from other perceptual dimensions, I created two instructions sets, asking observers either to rate the similarity of the targets alone or to rate the overall similarity of the target and mask compound. Thus I report results of two multidimensional scaling experiments, that only differ with respect to instructions, and of one discrimination/visibility experiment. As these three experiments are based on the same stimuli, and as the discrimination experiment was ran only as an aid to the interpretation of the multidimensional results, the three experiments will be described and analyzed conjointly.

2. Material and methods

2.1. Participants

Twenty-five observers from a pool of students (8 males, ages ranging from 19 to 26) participated in the Multidimensional scaling experiments, for one session that lasted approximately 45 min. A different group ($N = 21$, 9 males,

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ages ranging from 20 to 27) of similar observers participated in the one hour discrimination experiment. None were experienced psychophysical observer, and all were naive to the intent of the experiment. They all had normal or corrected to normal vision.

2.2. Stimuli

Observers sat 80 cm from a Sony Trinitron CRT screen with a refresh rate of 100 Hz and a resolution of 1024 × 768 pixels (pixel size: 0.0215°) in a dimly lit experimental booth. The target was a square (25 pixels, .54°), while the mask was a square annulus (35 pixels, outer width, .75°), with no intervening gap between the target and the mask. Stimuli were black (4 cd/m^2), while the rest of the screen was a light gray (23 cd/m^2). A trial (see Fig. 1A) consisted first of a fixation cross (.1°, 700 ms) at the center of the screen, then the two target–mask pairs, one above and one below fixation (eccentricity: .86°), with a fixed inter-pair interval of 500 ms. Durations of targets and masks were respectively 20 and 30 ms. Finally, a horizontal scale with seven cells appeared, of which only the endpoints were labeled as "Totally different" and "Perfectly alike" (in French, see below for the precise tasks and instructions). On each trial one random cell was highlighted. Observers moved the highlighted cell with the arrow keys on a standard keyboard, and validated their response with the space bar. In order to improve observers' judgment quality, they could replay the two pairs before entering their judgements. Five observers never did so, while the proportion of retries was .34 (*sd* = .36).

I used all SOAs in the range 0–150 ms in steps of 10 ms, and presented the full 16 × 16 combinations. Thus the pairs with different SOAs were presented twice (with position above or below fixation reversed), while the pairs with identical SOAs were presented once.

2.3. Procedure

To begin, observers were twice shown the full randomized list of target–mask pairs in a familiarization block where the two pairs above and below fixation were identical; observers were apprised of this and were instructed to practice the use of the scale by bringing the highlighted cell back to the "exactly identical" end. After these 32 trials, observers were presented the randomized 256 trials of the main scaling experiment, with *ad lib.* pauses every 32 trials.

2.4. Instructions

Two instruction sets were used: in the *holistic* instruction set, observers (*N* = 10) were asked to rate the global similarity of the two target–mask pairs. They were

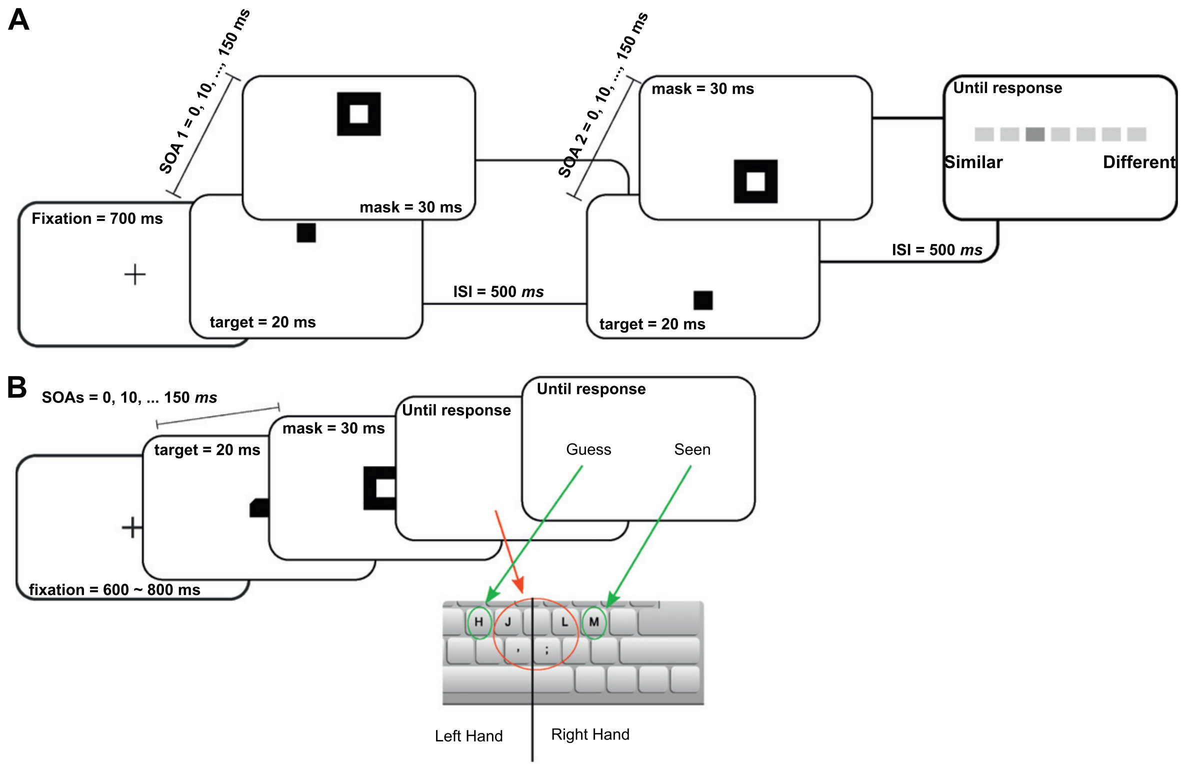

Fig. 1. (A) Trial structure for the main scaling experiment. Two target–mask pairs were shown, one above and one below fixation, and participants rated their similarity. Note that if participants were unsure about their response, they could replay the trial by hitting the *R* key on the scale screen. (B) Trial structure for the discrimination and visibility rating experiment. Notice the dent in one of the target's corner. For the discrimination task, participants used the *J*, *L*, comma and semi-colon keys (French keyboard, red color code); they used the *H* and *M* key for the visibility task (green color code). Sides for "seen"/ "not seen" were counterbalanced across participants. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

requested to consider each target – mask pair as a complex visual event, and to judge to what extent these two complex events were similar. In the *focal* instruction set observers ($N = 15$) were instructed to focus their judgements on the target and factor out the mask. Importantly, as is customary in multidimensional scaling procedure, the instruction sets did not highlight which aspect or dimension of the stimuli were to be used in the similarity ratings. Thus, instructions differed only with respect to *what* to observe, not about *how* to judge similarity.

2.5. Discrimination and visibility ratings

For the control discrimination experiment, stimuli matched those of the MDS experiment, except that the target had a small (.064°) notch in one corner. Following the methodology of Lau and Passingham (2006), on each trial (see Fig. 1B) observers first performed a four Alternative Forced Choice task on the position of the missing corner, and then reported whether they saw the target or simply guessed.

3. Results

3.1. Preliminary analyses: two dimensional MDS and discrimination results

First, I wanted to ascertain that the multidimensional scaling procedure was able to recover some well-known properties of metacontrast. To this end, I applied a classic two dimensional MDS and compared it to the results of the traditional discrimination and visibility experiment. For each stimulus pair, I averaged all similarity judgments (two repetitions per participants) over participants, for both instruction sets.[2] Here, I aggregated both instruction sets, as this was simply a preliminary analysis meant to assay the soundness of the technique. Responses on the similarity scale were coded linearly from 0 ("Identical") to 6 ("totally different"). I thus obtained a triangular matrix of dissimilarities which can be considered as distances. I then I submitted these distances to metric MDS, searching for a bidimensional configuration. I used the SMACOF package (De Leeuw & Mair, 2009) for the R statistical environment (R Development Core Team, 2009). Again, the choice of a 2-dimensions configuration is here simply preliminary, in order to check that there is indeed some structure in the data.

As can be seen (Fig. 2), this configuration is highly structured: increasing SOAs are distributed along a main axis, with some compression at the higher and lower ends of the interval. More precisely, we see that SOAs between 0 and 30 ms are nearly indistinguishable along this dimension, as are SOAs above 110 ms. On the contrary, SOAs between 40 and 100 ms are evenly spaced along this first dimension. A secondary axis seems to correspond to visibility, with intermediate SOAs, for which visibility of the target is known to be most impaired, being at one extreme

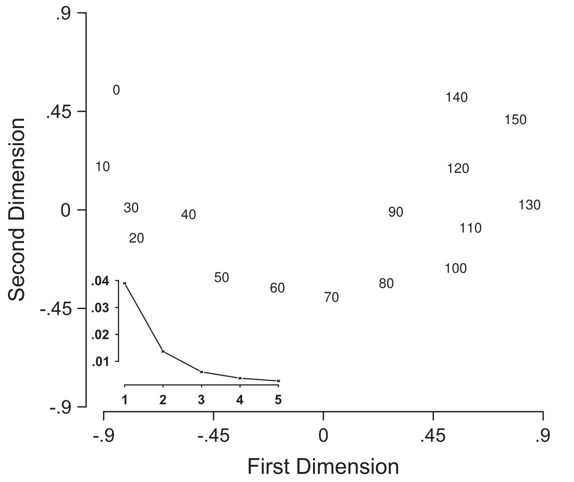

Fig. 2. Metric multidimensional scaling (MDS) two dimensional configuration for dissimilarity judgments averaged over all observers, in the two instruction sets. Numbers indicate SOAs. Inset represents the stress for the $N = 1, \ldots, 5$ dimensional solutions with classical metric MDS. As can be seen, there is a sharp reduction in stress from the 1 to the 2 dimensions solution, but some improvement with the 3 dimensions solution is also apparent.

and short and long SOAs at the other. I thus recover the U-shape of the metacontrast function: physical time is monotonously mapped onto perceptual time, and visibility emerges as a non-monotonic function of perceptual time. This confirms, by novel means, that the two main axes that organize the perceptual space of metacontrast are time and visibility.

This interpretation is vindicated by the analysis of the discrimination and visibility experiment: for this experiment, I excluded three participants whose performances were overall below 65% correct, and transformed both visibility estimates and discrimination performances to *d*'s, assuming no bias (Green & Dai, 1991). It yielded U-shaped metacontrast functions, for both measures (see Fig. 3). In a 16×2 repeated measures ANOVA with factors of SOA and response type, and observers as a random factor, the two main effects were found significant ($ps < 10^{-6}$), but the interaction was not ($p > .8$).

Then, I regressed positions on the secondary axis of the previous two dimensional MDS group analysis on discrimination performances and visibility judgments. Both regressions were found significant ($r = .81$, $p < .001$ and $r = .75$, $p < .001$ for visibility and discrimination performances respectively – see Fig. 4 for a plot of the regression of position on the second MDS dimension against visibility). Interestingly, visibility seemed a better predictor. Thus, even though the two measures come from different groups of participants, the correlation suggest that the second perceptual dimension in metacontrast is tightly linked to visibility of the target.

3.2. Impact of instructions

The previous analyses were conducted on dissimilarities averaged over participants and instructions sets. Recall

[2] Two observers from the "focal" instructions sets made clear during debriefing that they did not perform the task and were excluded from all analyses.

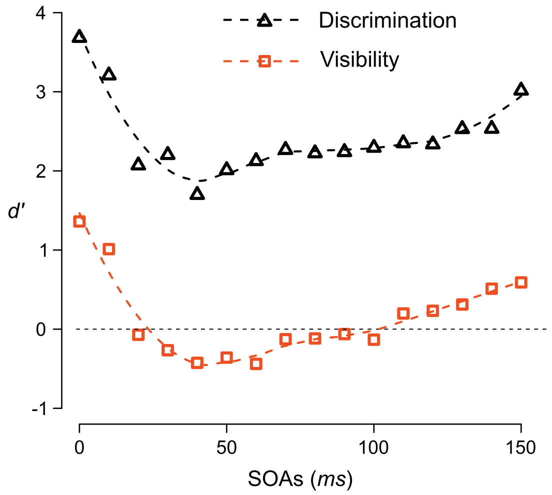

Fig. 3. Results for the discrimination/visibility experiment: *d'* transformed discrimination performances and visibility judgments are plotted against SOAs. Dotted lines are locally weighted scatterplot smoothing fits (LOESS, Cleveland, 1979). The minima are at 41 and 42.5 ms, and do not differ significantly ($p > .5$).

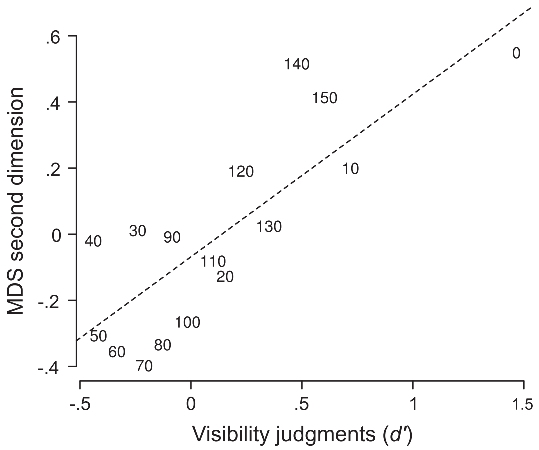

Fig. 4. For each SOA, position on the second dimension of the bidmensional MDS plotted against visibility (LOESS predictions of *d'*s). Dotted line is the regression line. Recall that both measures come from different groups of participants. An analogous regression on discrimination performances is virtually identical and not shown.

however that some participants were requested to rate the similarity of the targets only in two target–mask pairs (“focal” group), while others had to rate the global similarity of the two pairs (“holistic” group) – see Supplementary Fig. 1 online for the MDS configurations of the two groups. In order to assess whether the perceptual spaces elicited by the two judgments were different, I used the INDSCAL individual differences model (Carroll & Chang, 1970; De Leeuw & Mair, 2009). This model takes as input one matrix of distances per participant, and finds a group configuration – accounting for individual differences by assuming that each participant is characterized by individual weights on each dimension. Thus, I computed the 2 and 3 dimensional INDSCAL solutions with the “holistic” and “focal” groups as “individuals”. By construction the two configurations are in the same space, so that I could compute their overall distance as the sum of distances between homologous SOA points in the two configurations. I then compared this value to the distribution of the same statistic for 5000 bootstrap samples where each observer was randomly assigned to one or the other group. The actual sums of distance were at the .61 and .52 percentiles (in 2 and 3 dimensions respectively) of the bootstrap distributions, which strongly suggests that the two instructions sets elicited the same perceptual judgments. Thus, whatever the instructions, time and visibility are the two main dimensions of metacontrast percepts. Accordingly, in subsequent analyses, instructions sets are not taken into account.[3]

3.3. Three dimensional analyses

Although this interpretation is appealing, there are hints that the story might be more complex. Indeed, as can be seen in the inset of Fig. 2, there is a sharp drop in stress (the loss function in MDS, representing the amount of distortion introduced by the reduction of dimensionality) from the unidimensional to the bidimensional solution, but still the three dimensional solution seems to provide some improvement. Thus, I wanted to assess whether a higher dimensional MDS would yield informative results.

To this end, first, I computed a classic metric MDS on aggregated dissimilarity matrices with dimensionality $= 2, \ldots, 5$ and applied the jackknife procedure (de Leeuw & Meulman, 1986) as implemented in the SMACOF package (De Leeuw & Mair, 2009) in R. The value of the loss function was minimal for the 3 dimensions solution (8.227 as opposed to 9.482 and 11.64 for 2 and 4 dimensions) and the dispersion was also minimal for the 3 dimensions solution (.07 as opposed to .088 and .087), suggesting that the three dimensional solution was the most adequate. Second, I computed a matrix of the residuals for the two dimensional solution, as the difference, in each cell of the 16 × 16 matrix of similarities, between the observed dissimilarity and the dissimilarity in the MDS configuration. I reasoned that if the stress decrement in the three dimensional solution was simply due to the presence of an added parameter in the model, the residuals should only represent noise. Accordingly, the three dimensional solutions computed on the two dimensional solution augmented with random permutations of this noise should yield a comparable reduction of stress. However, quite the opposite happened: only 9.4% of the bootstrapped (5000 samples) distribution had smaller stress than the actual three dimensional solution.[4] This indicates that the

[3] As suggested by anonymous reviewers, it is also possible that naive observers did not follow the instructions in at least one condition. For instance they may have found the “focal” task too difficult and resorted to some version of the “holistic” task in its stead. In the Supplementary materials online, I present some analyses, and results for one trained observer, that do not seem to vindicate this interpretation.

[4] In order to deal with negative distances in the configuration + bootstrapped residuals matrices, I adopted the following very conservative approach: I considered all cases (9%) where the bootstrapped dissimilarity matrices had negative distances as having null stress.

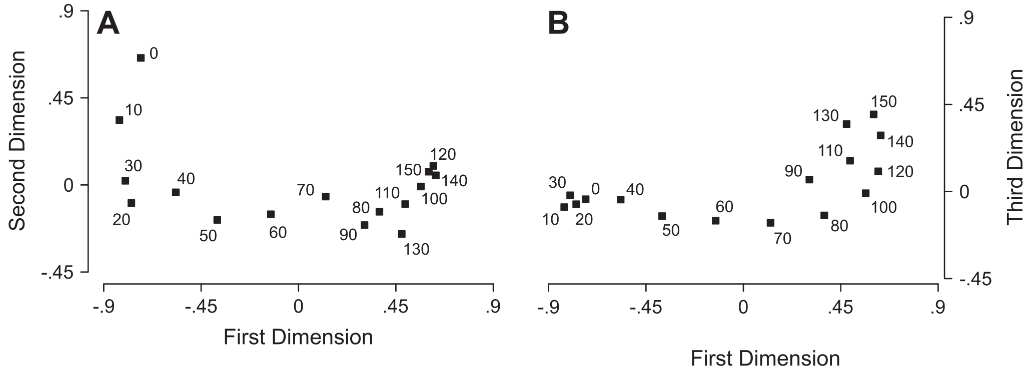

Fig. 5. Multidimensional scaling configurations for the 3 dimensions solution, computed with the INDSCAL model. Dimensions 2 (panel A) and 3 (panel B) are separately plotted against the first dimension. Numbers indicate SOAs.

matrix of residuals of the 2 dimensional solution does not represent random noise. Therefore, the 3 dimensional solution must reflect meaningful structure from participants' judgments. When applied to the three and four dimensional solutions, the same procedure yield strikingly different results, as the actual stress of the four dimensional solution was at the 88.2 percentile of the bootstrapped stress distribution. This analysis suggests that the reduction of stress from the three to the four dimensional solution is due to overfitting, while from two to three dimensions, it captures some structure of the data.

Hence, two methods pointed to the three dimensional solution as the most adequate. The three dimensional group configuration computed with the INDSCAL model is shown in Fig. 5A and B. As can be seen, the first dimension is again correlated with time, while the second and third dimensions correspond to the downward and upward branches of the U of the metacontrast function: short and intermediate SOAs are regularly spaced on the second dimension, while the third dimension discriminates among long SOAs. This suggests that, even though visibility may in some respect be equated across the trough of the metacontrast function, it still differs qualitatively between long and short SOAs.

4. Discussion

The following main results emerge from this first application of MDS to metacontrast: first, time is the most salient feature of the stimuli. The first dimension, both in the two and three dimensional solutions was an obvious monotonic function of the target–mask SOA, albeit compressed at the two ends. Importantly, even when observers were asked to focus only on the first visual event (the target) in the focal instructions set, their judgments still revealed a massive effect of the SOA.

It is difficult to ascertain here that the ordering of stimuli according to increasing SOAs corresponds indeed to any perceived duration. It might correlate with some visual property of the target or of the target–mask compound. However, notice that duration, being simply the SOA, is not confounded with visual energy, since the target and the mask are themselves of fixed durations. Thus duration here is unlikely to give rise to contrast or form summation (Kahneman, 1966). Moreover, we know that observers are sensitive to the duration of visual events in the range of our stimuli (Allan, Kristofferson, & Wiens, 1971). Thus, the interpretation of the first dimension as expressing a perception of duration seems the most parsimonious. Since the durations of the target and the mask were fixed, it is impossible to tell whether the relevant physical parameter is the total duration of the stimuli, the SOA or some other variable (for instance the inter-stimulus interval).

That observers could not abstract from the duration dimension when requested to do so, may be interpreted as showing that at the timescale of metacontrast, the two physical events are perceptually yoked. In that sense, metacontrast stimuli form a single complex visual event. It is important to realize in this respect that roughly one half of the stimuli (SOAs below 80 ms) are within the range of visual integration times (Eriksen & Collins, 1967; Hogben & di Lollo, 1974; Cass & Alais, 2006; Forget, Buiatti, & Dehaene, 2010). Thus, results show that even within the range where observers do not fully dissociate the target from the mask, they are sensitive to some overall temporal property of the stimulus.

The second dimension of the perceptual space of metacontrast corresponds quite closely to the visibility of the target. This should not come as a surprise, as metacontrast is most often measured with, and used for, the decrement in visibility it produces. The lowest point on the second dimension corresponds to the minimum in visibility as measured with very similar stimuli. However, the main novel result is that visibility itself is not unitary. The U of the U-shaped metacontrast function is twisted, so that its descending and ascending branches do not lie in the same perceptual plane. High visibility as a result of short SOAs and as a result of long SOAs are perceptually distinct, as revealed by the three dimensional analysis. While in some sense visibility can be equated for short and long SOAs, these two classes of stimuli would still differ in perceptual quality: visibility under decreasing integration is perceptually distinct from visibility under increasing segregation.

Recent studies (Albrecht, Klapötke, & Mattler, 2010; Bachmann, 2009; Breitmeyer et al., 2006; Jannati & Di

Lollo, 2011) have revived the notion of "criterion content" (Kahneman, 1968), according to which observers faced with a metacontrast stimulus must choose the most appropriate perceptual criterion in order to perform the task. Quite often, when the targets and masks are integrated, at short SOAs, the resulting shapes do not look like the targets in isolation – *cf* (Jannati & Di Lollo, 2011) for a precise analysis of the popular "diamond"/"square" stimuli. Thus, the configural basis of the decision in a discrimination experiment might differ at long and short SOAs, yielding obvious differences in criterion content. However, whereas this might be the case for the discrimination/visibility experiment (at short SOAs, the main visible feature might be a triangular "hole" in the target + mask compound) it is less so with the stimuli I used in the main MDS experiment: as the targets are always plain squares with no intervening gap, figural (Gestalt) cues are constant across all SOAs – Notice that since masks are longer than targets, this is true even at SOA = 0 ms. Yet, the perceptual dimension for short SOAs stimuli differs from the perceptual dimension of long SOAs stimuli, even beyond the domain of temporal overlap between target and mask. In other words, short and long SOAs visibilities do not look the same, and if requested to make a visibility judgment on a unidimensional scale, participants would in all likelihood not use the same criterion content across the trough of the metacontrast function.

Although the methodology is novel, the results are in agreement with some data and theories of metacontrast. First, they are reminiscent of what (Bernstein et al., 1976) obtained by means of discriminant function analysis: the authors were able to concluded that *as far as brightness judgments were concerned*, participants employed distinct criterion contents at short and long SOAs. In effect, they could show that at short SOAs, subjects relied on a subtraction between the brightness of the stimulus and of the mask, whereas at long SOAs brightnesses would add up. It is important to note, however that my experiments do not focus only on criterion content for brightness judgments, but tries to map out more broadly the perceptual space of metacontrast.

Second, my results fit perfectly within the framework of the dual processes theory of metacontrast (Reeves, 1982). Such a framework hypothesizes that the U-shape of the metacontrast function derives from averaging across trial over two opposite monotonic stochastic processes: one decreasing "target–mask integration" process, and one increasing "target–mask segregation" process.[5] (Reeves, 1982) conjoined, at the trial level, ordinal visibility judgments with binary simultaneity judgments, and was able to argue that the pattern of results did not favor a single-process account. My results also support a dual process account: the perceptual differentiation between the two branches of the metacontrast function can be construed as phenomenal counterpart to the two underlying processes. In further studies it should be possible to tighten the link between MDS approaches and the original methodology of Reeves (1982) by also collecting simultaneity judgments or temporal estimations.

As noted above, 80 ms seems a critical time constant in the dynamic properties of vision (Eriksen & Collins, 1967; Hogben & di Lollo, 1974; Cass & Alais, 2006; Forget et al., 2010). It is noteworthy that the third perceptual dimension discriminates SOAs above 80 ms, suggesting that when the mask and the target cease to be fully integrated, observers start perceiving their increasing separation. However, I should here acknowledge that the results found in the present study are probably specific to the chosen shapes for the target and the mask. Indeed, (Duangudom, Francis, & Herzog, 2007; see also Francis & Cho, 2008) have shown that the shape of the metacontrast function, as estimated from a forced choice task, depended heavily on the particular shapes of both the target and the mask. Similarly, it is a well established fact (for a recent review, see for instance (Breitmeyer & Öğmen, 2006, pp. 48–50)) that the shape of the metacontrast function depends on the target/mask energy ratio. All of this should make it clear that the three dimensional analysis is most probably dependent on type B (U-shaped) metacontrast, which in turn depends on precise configural and energy conditions for both the mask and the target.

Garner (1974) urged that we should distinguish "integral" from "separable" dimensions in perception, according to the effort required to perceptually resolve them. The above results strongly suggest that time and visibility are *integral* dimensions of metacontrast percepts: First, observers were in fact never able to abstract the time dimension; second, visibility came in two guises that were tightly linked to distinct portions of the perceived duration dimension.

These results have some implications regarding the use of metacontrast in the study of visual awareness and its neural underpinnings. Metacontrast is perhaps a dead alley in the quest for an experimental paradigm designed to yield a control on pure visibility, for at least two reasons, in addition to the fact that "absolute" invisibility of the target is almost never achieved, except in specific paradigms (Otto et al., 2006): first, duration of the target–mask pair cannot be ignored by observers. Visible and invisible targets will always be embedded in time varying percepts. Second, and more importantly, if one wishes to abstract over performance differences by relying on divergent visibilities across the trough of the metacontrast function ("relative blindsight", Lau & Passingham, 2006), one will in fact rely on very different percepts, one corresponding to an integrated target–mask pair, the other to a segregated pair.

Even phenomenologically inspired measures of visibility should be regarded with caution: indeed, measures such as the Perceptual Awareness Scale (PAS, Ramsøy & Overgaard, 2004; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010), which uses the four categories "No experience", "Brief glimpse", "Almost clear image", "Absolutely clear image" are readily construed as ordinal scales. While observers might well be able to project, in a systematic fashion, their bidimensional visibility percept on a unidimensional scale, it should not obscure the fact that the dynamics of vision creates complex percepts whose

[5] Note that (Reeves, 1982) also allows for a "no target" process, in order to account for trials were the target is invisible.

dimensions are probably very difficult to separate. In view of this result, it is certainly safer to construe visibility judgments as the resultant of a series of cognitive processes than as reports on an elementary perceptual quality.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2012.09.013.

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