Der Einfluss kognitiver Kontrollmechanismen auf das Gedächtnis

Integrationsarbeit im Rahmen der kumulativen Dissertation

Michèle Christine Muhmenthaler

Institut für Psychologie, Universität Bern

Author Note

Michèle C. Muhmenthaler, Institut für Psychologie, Universität Bern.

Korrespondenzadresse: Michèle Muhmenthaler, Fabrikstrasse 8, 3012 Bern,

michele.muhmenthaler@psy.unibe.ch

Zusammenfassung

Die kognitive Kontrolle beeinflusst nicht nur die unmittelbare Leistung, sie hat auch Konsequenzen auf die nachfolgende Gedächtnisleistung. Das Ziel dieser Arbeit ist es, drei Studien, die im Rahmen meiner Dissertation entstanden sind, zu integrieren und der Frage nachzugehen, wie verschiedene kognitive Konflikte während der Kodierung die Gedächtnisleistung beeinflussen. In der ersten Studie fanden wir Evidenz, dass Aufgabenwechsel und Bivalenz das Gedächtnis verschlechtern, was auf eine ineffiziente Aufmerksamkeitslenkung während hohen Kontrollanforderungen schliessen lässt. In der zweiten Studie wurden kognitive Konflikte in der Lernphase kombiniert. Wir replizierten in vier Experimenten, dass die Gedächtnisleistung durch Aufgabenwechsel reduziert wird. Ein Konflikt auf der Antwortebene resultierte hingegen in einem Gedächtnisvorteil. In der dritten Studie führten antwortkongruente (i.e., Stimuli, die in verschiedenen Aufgaben dieselbe Antworttaste verlangen) zu einer besseren Gedächtnisleistung als antwortinkongruente Stimuli, dies aber nur nach einem langen Intervall zwischen Lern- und Testphase. Den Effekt schrieben wir einem während der Lernphase entstandenen Schema für die kombinierten Stimuluskategorien zu, welches zu einer präferierten Konsolidierung führte. In der Diskussion werden die Resultate mit verschiedenen kognitiven Theorien und neuropsychologischen Modellen in Bezug gesetzt.

Der Einfluss kognitiver Kontrollmechanismen auf das Gedächtnis

Die kognitive Kontrolle ermöglicht dem Menschen ein zielorientiertes Verhalten, indem Denken und Handeln willentlich gesteuert werden. Sie reguliert aber nicht nur das momentane Verhalten, sie hat auch längerfristige Konsequenzen auf das Gedächtnis. In jüngerer Forschung wurden gezielt Kontrollmechanismen manipuliert und anschliessend die Gedächtnisleistung erhoben, um den Einfluss der kognitiven Kontrolle auf das Gedächtnis zu untersuchen. Die Resultate zeigten unterschiedliche Befunde, nämlich führten höhere kognitive Anforderungen in manchen Studien zu einer besseren und in anderen zu einer schlechteren Gedächtnisleistung (Krebs, Boehler, De Belder, & Egner, 2015; Ortiz-Tudela, Milliken, Botta, LaPointe, & Lupiañez, 2017; Richter & Yeung, 2012, 2015; Rosner, D'Angelo, MacLellan, & Milliken, 2015; Rosner, Davis, & Milliken, 2015). Dies impliziert, dass die kognitiven Kontrollanforderungen differenziert betrachtet werden müssen. Das Ziel meiner Dissertation war, systematisch den Einfluss verschiedener kognitiver Konflikte auf das Gedächtnis zu untersuchen. Die vorliegende Arbeit beinhaltet drei empirische Studien, die meiner kumulativen Dissertation zugrunde liegen.

Kognitive Kontrolle

Kognitive Konflikte führen zu erhöhten Kontrollanforderungen und gehen mit Leistungseinbussen einher, wobei sich die Konflikte auf der Stimulus-, der Antwort- oder der Aufgabenebene befinden können. Durch den Einsatz kognitiver Kontrolle wird das Verhalten flexibel an die spezifischen Konflikte angepasst. Dabei werden handlungsrelevante Informationen präferiert verarbeitet, konkurrierende Informationen inhibiert, sowie habituelle oder dominante Antworten überschrieben (Cohen, Braver, &

O'Reilly, 1996; Shiffrin & Schneider, 1977). Die kognitive Kontrolle beruht auf einem

kapazitätslimitierten Aufmerksamkeitssystem (MacDonald, Cohen, Stenger, & Carter,

2000). Kognitive Kontrollprozesse sind auch notwendig, um Handlungen über mehrere

Teilschritte hinweg auf ein übergeordnetes Ziel zu planen (Smith & Jonides, 1999). Um

diese Prozesse ausführen zu können, ist es nötig, die Handlungsziele in einem aktiven

Status zu halten (Cohen et al., 1996). All diesen Aspekten der *top-down-*

Informationsverarbeitung ist gemeinsam, dass sie stark mit dem präfrontalen Kortex

(PFC) assoziiert sind, betont wurden vor allem Regionen des lateralen und medialen PFC

(Desimone & Duncan, 1995; Niendam et al., 2012; Sakai, 2008; Yeung, 2013). Nicht

kritisch ist der PFC hingegen für einfaches, automatisches Verhalten wie die Orientierung

zu einem unerwarteten externen Stimulus, welches *bottom-up-*Informationsverarbeitung

widerspiegelt. Dieses Verhalten wird vor allem durch die Art der Stimuli und deren

automatischen Antworten determiniert (Miller & Cohen, 2001).

      Neben diesen regulierenden Fähigkeiten benötigt die kognitive Kontrolle auch

eine evaluative Komponente, die die Informationsverarbeitung überwacht und bei

Handlungsbedarf entsprechend einschreitet (Botvinick, Braver, Barch, Carter, & Cohen,

2001). Diese Komponente wurde gemäss Botvinick und Kollegen in den meisten

Modellen der kognitiven Kontrolle vernachlässigt (Baddeley & Della Sala, 1996; Cohen,

Dunbar, & McClelland, 1990; Norman & Shallice, 1986). Die Autoren stellten daher die

Hypothese der Konfliktüberwachung auf. Gemäss dieser erfolgen als Reaktion auf einen

auftretenden Konflikt kompensatorische Anpassungen mit dem Ziel, den Konflikt zu

reduzieren. Als wichtigste Struktur zur Konfliktüberwachung wurde der anteriore

zinguläre Kortex (ACC) identifiziert (Botvinick, Nystrom, Fissell, Carter, & Cohen,

1999; MacDonald et al., 2000). Der ACC liegt bilateral im medialen PFC um das Rostrum des Korpus Kallosum herum. Bildgebende Studien zeigten Aktivität im ACC in drei Situationen, erstens solchen, in denen eine dominante Antwort überschrieben werden muss (z.B. Pardo, Pardo, Janer, & Raichle, 1990), zweitens wenn gleichwertige Antwortalternativen konkurrieren (z.B. Barch, Braver, Sabb, & Noll, 2000) und drittens, wenn Fehler bemerkt werden (z.B. Carter et al., 1998; Kiehl, Liddle, & Hopfinger, 2000). Nach der Entdeckung eines Fehlers sind während einer kurzen Zeit die korrekte und falsche Antwort gleichzeitig aktiviert (Yeung, Botvinick, & Cohen, 2004). Somit ist allen ACC-aktivierenden Situationen gemeinsam, dass mehrere inkompatible Repräsentationen simultan aktiviert sind (Botvinick, Cohen, & Carter, 2004; Egner & Hirsch, 2005).

Das kognitive Kontrollsystem beinhaltet demnach zwei dissoziierbare Komponenten, die eine regulative Feedback-Schleife bilden (MacDonald et al., 2000; Miller & Cohen, 2001). Die konfliktüberwachende, evaluative Komponente ist assoziiert mit dem ACC und signalisiert der regulierenden Komponente im dorsolateralen PFC (DLPFC), wenn inkompatible Antworttendenzen entdeckt werden. Dadurch wird Aufmerksamkeit rekrutiert, die selektiv auf aufgabenrelevante Information gelenkt wird, um den spezifischen Konflikt zu lösen. Dieser kompensatorische Mechanismus wirkt über eine neuronale Verstärkung von aufgabenrelevanter Information, nicht über eine Inhibition von aufgabenirrelevanter Information (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Egner & Hirsch, 2005).

Paradigmen

Zur Untersuchung der kognitiven Kontrolle wurden Paradigmen entwickelt, in denen kognitive Konflikte in manchen Trials mehr kontrolliertes Verhalten auslösen als

in anderen Trials. Durch Kontrastierung der konfliktbehafteten Trials mit den einfacheren

Trials können Aussagen über den Kontrollbedarf getroffen werden. Verschiedene

Paradigmen zur experimentellen Untersuchung von kognitiven Kontrollprozessen haben

sich etabliert, dazu gehören das Aufgabenwechsel-Paradigma (im folgenden *Task

Switching* genannt; Allport, Styles, & Hsieh, 1994; Jersild, 1927; Rogers & Monsell,

1995), die Stroop-Aufgabe (Stroop, 1935), die Flanker-Aufgabe (Eriksen & Eriksen,

1974) sowie die Simon-Aufgabe (Simon, 1990). Für die vorliegende Integration sind das

Task-Switching- sowie das Stroop-Paradigma relevant, da wir Konflikte untersuchten, die

auf diesen Paradigmen basieren. Im Folgenden werden diese näher beschrieben.

  Task Switching. Mit Task-Switching-Prozeduren können im Labor die kognitive

Flexibilität sowie zielorientiertes Verhalten untersucht werden. In diesem Paradigma

wechseln die Versuchspersonen (Vpn) zwischen zwei (oder mehreren) Aufgaben, dabei

werden meist bivalente Stimuli verarbeitet. Bivalente Stimuli sind Stimuli, die für beide

Aufgaben relevant sind, univalente Stimuli können hingegen nur in einer Aufgabe

verarbeitet werden. Aufgabenwechsel gehen sehr stabil und robust mit Kosten in Form

von längeren Reaktionszeiten und höheren Fehlerraten einher, den sogenannten *Switch-

Kosten* (Allport et al., 1994; Meiran, 1996; Rogers & Monsell, 1995). Diese gelten als

Mass für die Differenz in ausgeübter kognitiver Kontrolle für Trials, in denen sich die

Aufgabe wiederholt (i.e., *Repeat-Trials*) vs. in denen die Aufgabe wechselt (i.e., *Switch-

Trials*). Zahlreiche Arbeiten befassten sich mit der genauen Definition dieser Kosten und

bis heute besteht kein klarer Konsensus (für ein Review, siehe Kiesel et al., 2010).

Zusammenfassend lässt sich aber sagen, dass sich Wechselkosten zumindest teilweise mit

der Implementierung der neuen Aufgabe erklären lassen (Rogers & Monsell, 1995). Bei

Wechseln mit bivalenten Stimuli bleiben jedoch auch bei langer Vorbereitungszeit Switch-Kosten bestehen. Diese residualen Kosten reflektieren gemäss Allport et al. (1994) eine *bottom-up* gesteuerte proaktive Interferenz, die aus der konkurrierenden Stimulus-Antwort-Zuweisung resultiert. Gemäss Woodward, Meier, Tipper und Graf (2003) reflektieren die verbleibenden Kosten hingegen die *top*-down gesteuerte Ressourcen kostende Selektion der korrekten Aufgabe, die einen vorsichtigeren Antwortstil zur Folge hat. Bivalente Stimuli verursachen daher mehr Kosten bei einem Aufgabenwechsel als univalente Stimuli (Jersild, 1927; Meiran, 2008). Der unterschiedliche Einfluss von Aufgabenwechseln mit univalenten vs. bivalenten Stimuli auf das Gedächtnis lag im Fokus unserer ersten Studie (Muhmenthaler & Meier, 2019).

Bildgebende Studie zeigten während Task-Switching ein breites Netzwerk an Aktivität in präfrontalen sowie parietalen Regionen (Kim, Cilles, Johnson, & Gold, 2012; Niendam et al., 2012; Yeung, Nystrom, Aronson, & Cohen, 2006). Wurden Aufgabenwechsel mit Wiederholungen kontrastiert, zeigte sich erhöhte Aktivierung in lateralen und medialen Regionen des PFC sowie im superioren Parietalcortex (Kimberg, Aguirre, & D'Esposito, 2000). Als wichtigstes neuronales Substrat wurde der DLPFC identifiziert (Braver, Reynolds, & Donaldson, 2003).

Stroop-Paradigma. In der klassischen Stroop-Aufgabe (MacLeod, 1991; Stroop, 1935) müssen die Vpn die Schriftfarbe eines geschriebenen Farbworts nennen, während das Wort ignoriert werden muss. In inkongruenten Trials (z.B. das Wort ROT in grüner Schrift) konkurrieren zwei Farbantworten und das automatisch ablaufende Lesen muss überschrieben werden, was kognitive Kontrolle rekrutiert. Diese Adjustierung lässt sich in Form von Reaktionszeiten messen, indem inkongruente mit kongruenten Trials

kontrastiert werden (Egner, 2017). Da in inkongruenten Trials zwei unterschiedliche

Antworten aktiviert sind (z.B. rot und grün), entsteht ein Antwortkonflikt (Kerns, 2006).

Neuropsychologische Studien zeigten eine ACC-Aktivierung bei inkongruenten Trials,

was die Entdeckung und Überwindung dieses Konflikts reflektiert (Bench et al., 1993;

Egner & Hirsch, 2005; Pardo et al., 1990; Yeung et al., 2004).

Es wurden Aufgaben entwickelt, die dem Stroop-Paradigma angelehnt sind, die

aber aus zwei *gleich* dominanten Antwortalternativen bestehen, beispielsweise aus zwei

Wörtern, wobei nur eines der beiden beachtet und das andere ignoriert werden muss (vgl.

Rosner, D'Angelo et al., 2015). Nur die entsprechende Instruktion entscheidet, welcher

Aspekt des Stimulus' relevant oder irrelevant ist. Bei inkongruenten Trials entsteht

ebenfalls ein Antwortkonflikt, da die Wörter unterschiedliche Antworten erfordern. In

unserer zweiten Studie untersuchten wir einen solchen Konflikt (Muhmenthaler & Meier,

2019b).

Gedächtnis

Das Langzeitgedächtnis hat im Gegensatz zum Kurzzeitgedächtnis eine

unendliche Speicherkapazität und ist konstruktiv, dabei aber auch anfällig für Fehler

(Dudai & Morris, 2013). Läsionsstudien an Tieren, Patientenstudien sowie bildgebende

Studien konnten zeigen, dass der mediale Temporallappen (MTL) kritisch ist für die

Bildung von deklarativem Langzeitgedächtnis. Bilaterale Läsionen des Hippocampus und

umliegenden Strukturen führen zu einer anterograden Amnesie, keine neuen Inhalte

können aufgenommen werden (Scoville & Milner, 1957). Entfernte Erinnerungen bleiben

hingegen intakt, sie sind nicht mehr Hippocampus abhängig und in einem weit verteilten

Netzwerk im Neokortex gespeichert (Dudai, Karni, & Born, 2015; Kumaran, Hassabis, &

McClelland, 2016).

Gemäss der *Complementary Learning Systems*-Theorie von McClelland,

McNaughton und O'Reilly (1995) wird ein neuer deklarativer Gedächtnisinhalt zuerst im

schnell lernenden Hippocampus-System gespeichert, durch Reorganisation werden die

Inhalte graduell in verschiedene Strukturen in den Neokortex übertragen und sukzessiv

weniger Hippocampus abhängig (Squire, Genzel, Wixted, & Morris, 2015). Der Dialog

zwischen Hippocampus und Neokortex wird auf der neuronalen Ebene durch eine

Reaktivierung der neu erworbenen Repräsentationen geführt, die im Hippocampus

transient gespeicherten Episoden werden vor allem im Tiefschlaf reaktiviert (Diekelmann

& Born, 2007; Stickgold, 2005). Neuere Evidenz weist aber auch auf einen neuronalen

Replay während dem *Rapid Eye Movement* (REM) Schlaf hin, dies vor allem wenn

kontextuelle, emotionale oder örtliche Gedächtnisinhalte konsolidiert werden (Boyce,

Glasgow, Williams, & Adamantidis, 2016; Durrant, Cairney, McDermott, & Lewis,

2015; Nishida, Pearsall, Buckner, & Walker, 2008).

Läsionsstudien an Ratten lieferten Evidenz, dass neue Assoziationen rasch

(innerhalb von 48 Stunden) in neokortikale Strukturen integriert werden können und

Hippocampus unabhängig werden, wenn diese konsistent mit vorher erlernten Schemata

sind (Tse et al., 2007; Tse et al., 2011; Wang & Morris, 2010). Schemata sind

semantische Wissenseinheiten, welche im Lauf einer Interaktion mit der Umwelt gebildet

werden, um Erfahrung zu organisieren (Bartlett, 1935; Gilboa & Marlatte, 2017; Piaget,

1952; Rumelhart, 1984). Sie spielen bei der Gedächtniskonsolidierung beim Menschen

ebenfalls eine wichtige Rolle. McClelland (2013) integrierte die Wichtigkeit von

semantischem Vorwissen in seine Konsolidierungstheorie und betonte, dass eine

angelegte Wissensstruktur eine schnellere Integration von Inhalten in den Neokortex

ermögliche als bisher angenommen. Schema-inkonsistente Information werde hingegen

langsamer konsolidiert, um «katastrophale Interferenz» zu vermeiden.

Die Gedächtnisleistung kann per Rekognition oder mittels freien Abrufs erhoben

werden. Man geht heute davon aus, dass die Rekognition auf zwei distinkten Prozessen

beruht, dem kontextfreien Wiedererkennen, welches mit einem Gefühl von Vertrautheit

(*familiarity*) assoziiert ist, sowie dem kontextbasierten Erinnern (*recollection*), welches

mit Details der erinnerten Episode einhergeht (Yonelinas, 2002). Die beiden Begriffe

können als unterschiedliche Abrufprozesse verstanden werden, wobei *familiarity*

schneller und automatischer abläuft als *recollection*, welches aufwendiger ist (Atkinson,

Hertmann, & Wescourt, 1974). Die subjektive Einschätzung der Qualität der

Erinnerungen kann mittels *remember/know*-Paradigma erhoben werden, welches zur

Operationalisierung dieser beiden Abrufprozesse von Tulving (1985) entwickelt wurde.

Der freie Abruf ist ähnlich wie *recollection*, jedoch anstrengender und schwieriger, da

keine Hinweisreize vorhanden sind und daher mehr selbst initiierte Prozesse nötig sind

(Craik, & McDowd, 1987).

Kognitive Kontrolle und Gedächtnis. Das Langzeitgedächtnis und die kognitive

Kontrolle sind verknüpft und interagieren auf die verschiedensten Weisen (Chun & Turk-

Browne, 2007). So beeinflusst das Gedächtnis die kognitive Kontrolle, indem die

Erfahrung bestimmt, welche Stimuli als relevant wahrgenommen werden (Becker &

Rasmussen, 2008). Kognitive Konflikte während der Kodierung beeinflussen das

Gedächtnis ebenso, sie können das Gedächtnis verschlechtern (Craik, Govoni, Naveh-

Benjamin, & Anderson, 1996; Reynolds, Donaldson, Wagner, & Braver, 2004),

verbessern (Krebs et al., 2015; Rosner, D'Angelo et al., 2015) sowie die

Gedächtnisselektivität beeinflussen (Chiu & Egner, 2016; Richter & Yeung, 2012, 2015).

Konflikte während des Erinnerns können sich ebenfalls auf das Gedächtnis auswirken

(z.B., Wais, Rubens, Boccanfuso, & Gazzaley, 2010). In der vorliegenden

Integrationsarbeit standen jedoch Gedächtniseffekte durch verschiedene kognitive

Konflikte während der Kodierung im Zentrum.

Allgemeine Methode

Zahlreiche Studien untersuchten die Effekte von Aufgabenwechsel, Inkongruenz

oder Bivalenz durch Messen von Reaktionszeiten und Erhebung der Fehlerraten auf die

unmittelbare Leistung im entsprechenden, im vorherigen Trial oder in nachfolgenden

Trials (Egner, 2007, 2017; Gratton, Coles, & Donchin, 1992; Kim & Cho, 2014; Meier,

Woodward, Rey-Mermet, & Graf, 2009; Rey-Mermet & Meier, 2014, 2017; Verguts,

Notebaert, Kunde, & Wühr, 2011). Unser Ziel war es, diese Konfliktarten auf das

Langzeitgedächtnis zu untersuchen. Hierzu verwendeten wir ein Paradigma, welches eine

Lernphase mit einer unangekündigten Testphase verbindet, in der die Gedächtnisleistung

erhoben wird. Task-Switching wurde mit diesem Paradigma bereits von Reynolds et al.

(2004) sowie von Richter und Yeung (2012, 2015) untersucht, die Effekte von

Antwortkonflikten von Rosner, D'Angelo et al. (2015) und Krebs et al. (2015).

In meinem Dissertationsprojekt knüpften wir an diesem Punkt an und erweiterten

die Forschung, indem wir erstmals auch univalente Stimuli in einem Task-Switching-

Paradigma einsetzten (Muhmenthaler & Meier, 2019a). Ausserdem kombinierten wir

erstmals verschiedene Konfliktarten. Eine weitere bisherige Limitation war, dass als

Erinnerungsmass stets die Rekognition verwendet worden war, wir erhoben die

Gedächtnisleistung aber zusätzlich mittels freien Abrufs (Muhmenthaler & Meier,

2019b). Als dritte wichtige Erweiterung des Paradigmas nutzten wir längere Intervalle

zwischen Lern- und Testphase, um Konsolidierungseffekte einzubeziehen

(Muhmenthaler & Meier, submitted). Im Folgenden wird in einzelnen Abschnitten auf die

drei Studien eingegangen. In der ersten Studie wurde der Forschungsfrage nachgegangen,

wie ein Aufgabenwechsel mit univalenten sowie bivalenten Stimuli die nachfolgende

Rekognitionsleistung beeinflusst. In der zweiten Studie wurde untersucht, wie sich

unterschiedliche Konflikte kombiniert auf den freien Abruf auswirken. Die dritte Studie

untersuchte den Einfluss von Antwortkongruenz auf eine unmittelbare und eine spätere

Rekognitionsleistung.

Der Einfluss von Task-Switching mit univalenten und bivalenten Stimuli auf

die Rekognition

Die erste Studie befasste sich mit der Fragestellung, ob sich ein Aufgabenwechsel

grundsätzlich zu besserem, oder schlechterem Gedächtnis führt als eine

Aufgabenwiederholung. Ein Aufgabenwechsel führt wie bereits erwähnt zu höheren

Kontrollanforderungen als eine Aufgabenwiederholung, zudem sind die Anforderungen

mit bivalenten Stimuli höher als mit univalenten Stimuli (Allport et al., 1994; Meiran,

2008; Woodward et al., 2003). Dies könnte zu einer Aufmerksamkeitsfokussierung auf

die Stimuli führen, was die Gedächtnisleistung verbessern könnte (Botvinick et al., 2001).

Andererseits könnte ein Aufgabenwechsel die Aufmerksamkeitsfokussierung reduzieren,

da die Aufmerksamkeitsressourcen den zusätzlichen Operationen auf der Aufgabenebene

gewidmet werden müssen (Dreisbach & Wenke, 2011; Reynolds et al., 2004). Bisherige

Studien fanden eine schlechtere Gedächtnisleistung bei Aufgabenwechseln (i.e., in Switch-Trials), jedoch waren bisher nur bivalente und meist zusammengesetzte Stimuli untersucht worden (Reynolds et al., 2004; Richter & Yeung, 2012, 2015). Wir untersuchten erstmals auch univalente Stimuli.

Die Vpn wechselten in zwei Experimenten in einer vorhersagbaren Sequenz zwischen zwei Kategorisierungsaufgaben mit Wörtern und Bildern (siehe Tabelle 1), danach wurde ein nicht angekündigter Rekognitionstest durchgeführt. Zudem fragten wir die Vpn mittels *remember-know*-Paradigma, ob ihre Antworten eher auf Vertrautheit (*know*-Antworten) oder auf einer genauen Erinnerung (*remember*-Antworten) basierten (Tulving, 1985; Yonelinas, 2002). Die Resultate zeigten, dass sich ein Aufgabenwechsel negativ auf die Gedächtnisleistung auswirkte. Der Effekt war stärker in dem Experiment mit bivalenten Stimuli, was reflektierte, dass Bivalenz zusätzliche Kosten beim Wechseln verursachte. Des Weiteren zeigte sich, dass Repeat-Stimuli öfter zu *remember*-Antworten führten als die Switch-Stimuli, die *know*-Antworten waren über die Bedingungen hingegen konstant. Frühere Forschung hat gezeigt, dass reduzierte Aufmerksamkeit während der Kodierung weniger *remember*-Antworten zur Folge hat bei gleichbleibenden *know*-Antworten (Gardiner & Parkin, 1990; Yonelinas, 2002). Dies erhärtet den Erklärungsansatz, dass Aufgabenwechsel sowie Bivalenz zu einer reduzierten Aufmerksamkeitsfokussierung auf die Stimuli führen, der Effekt für die *remember*-Antworten war mit bivalenten Stimuli deutlich stärker.

Der Einfluss verschiedener Konflikte auf den freien Abruf

In dieser Studie wurden erstmals verschiedene kognitive Konflikte in einer Lernphase kombiniert, um eine Gedächtnisverbesserung sowie eine Gedächtniseinbusse

für spezifische Zielstimuli zu generieren. Aufgabenwechsel waren bisher immer mit einer

Leistungseinbusse für Zielstimuli einhergegangen, während inkongruente Stimuli die

Gedächtnisleistung durch selektive Aufmerksamkeitsmechanismen zu verbessern

schienen (Krebs et al., 2015; Rosner, D'Angelo et al., 2015). Wir stellten die Hypothesen

auf, dass Switch-Stimuli schlechter erinnert werden als Repeat-Stimuli, während

inkongruente Stimuli besser erinnert werden als kongruente.

　　　In vier Experimenten wechselten die Vpn in der Lernphase zwischen zwei

Wortkategorisierungs-Aufgaben in einer vorhersagbaren Sequenz, siehe Tabelle 1. Die

Stimuli bestanden aus zwei verschachtelten, verschiedenfarbigen Wörtern. Das rote Wort

musste kategorisiert werden, während das grüne Wort ignoriert werden musste (vgl.

Rosner, D'Angelo et al., 2015). Durch Auswechseln der Distraktor-Kategorie (das grüne

Wort) konnten unterschiedliche Arten von Kongruenz zwischen Ziel-und Distraktorwort

erzeugt werden, was wiederum verschiedene Arten von Konflikten generierte. Nach der

Lernphase wurde die freie Abrufleistung erhoben.

　　　Wir konnten in allen Experimenten replizieren, dass ein Aufgabenwechsel zu

einer schlechteren Gedächtnisleistung führt. Die Kongruenz-Manipulationen führten

hingegen zu verschiedenen Befunden. Die Resultate zeigten, dass inkongruente Stimuli

die Abrufleistung nur verbessern konnten, wenn sich der Konflikt wie in den Studien von

Krebs et al. (2015) und Rosner, D'Angelo et al. (2015) auf Ebene der Antwortkategorie

befand, wenn also beide Wörter verschiedene Antworten erforderten. Damit dieser

Konflikt aber eine förderliche Wirkung auf das Gedächtnis entfalten konnte, mussten die

Vpn zusätzlich in der Lage sein, die Aufmerksamkeit selektiv auf das Zielwort richten zu

können. Dies erreichten wir durch eine geblockte Präsentation der kongruenten und

inkongruenten Stimuli. Wurden die Stimuli randomisiert dargeboten, schienen die Vpn

keine spezifischen Strategien anzuwenden, was zu einer vergleichbaren

Gedächtnisleistung für kongruente und inkongruente Zielwörter führte.

Im Experiment 1 befand sich der Konflikt auf der perzeptuellen Ebene (zwei

verschiedenen Wörter wurden gezeigt anstatt zwei identische), was zu einer

Gedächtniseinbusse für inkongruente Zielwörter führte. Vermutlich generierte die

inkongruente Bedingung mehr Interferenz (das Target musste sozusagen gesucht

werden), was die Aufmerksamkeitsfokussierung auf das Zielwort reduzierte (Lavie,

2005). Da es aber keine Baseline gab (z.B. durch die Präsentation eines einzelnen

Wortes), wäre auch eine *Verbesserung* der Gedächtnisleistung durch die doppelte

Präsentation eines Wortes denkbar.

Die Resultate zeigten insgesamt, dass Inkongruenz klar definiert werden muss.

Nur wenn sich der Konflikt auf der Antwortebene befindet, kann das Gedächtnis

profitieren. Zusammenfassend lassen sich sämtliche Resultate wieder über die

Aufmerksamkeitsallokation erklären. Wird Aufmerksamkeit vom Stimulus abgezogen,

weil eine visuelle Ablenkung besteht oder weil eine neue Aufgabe implementiert werden

muss, wird die Abrufleistung schlechter. Die Detektion eines Antwortkonflikts hingegen

hat eine Aufmerksamkeitsfokussierung auf den Zielstimulus zur Folge, was die

Abrufleistung verbessern kann (Botvinick et al., 2001; Egner & Hirsch, 2005).

Antwortkongruenz und konsolidiertes Gedächtnis

In der dritten Studie untersuchten wir den Einfluss von *Antwortkongruenz* auf die

Rekognitionsleistung. Antwortkongruenz kann induziert werden, indem in einer Task-

Switching-Prozedur bivalente Stimuli zum Einsatz kommen und für beide Aufgaben

dieselben Antwortalternativen verwendet werden. Antwortkongruente Stimuli sind

demnach bivalente Stimuli, die in jedem Aufgabenkontext dieselbe Antworttaste

erfordern, antwortinkongruente Stimuli erfordern hingegen je nach Aufgabenkontext

unterschiedliche Antworttasten.

     In dieser Studie verwendeten wir dieselbe Prozedur wie in der ersten Studie

(Experiment 2), mit dem Unterschied, dass wir den Rekognitionstest zusätzlich nach

einer Woche durchführten. Wir wollten der Frage nachgehen, ob durch

Antwortkongruenz sozusagen *adhoc*, während der Lernphase, ein neues Schema

entstehen kann (Bartlett, 1935). Ein neues Schema entsteht durch die wiederholte

kombinierte Darbietung von Inhalten. Es wurden daher zwei Stimuluskategorien zu einer

kongruenten Antwortkategorie kombiniert. Die Vpn mussten in zwei Experimenten

einzelne Objekte auf Farbfotografien abwechselnd nach Grösse und Belebtheit beurteilen

(siehe Tabelle 1). Objekte, die *grösser als ein Ball* sowie *belebt* waren, waren

antwortkongruent, da beide Kategorien die *a*-Taste verlangten. Dasselbe galt für Objekte,

die *kleiner als ein Ball* sowie *unbelebt* waren, beide Kategorien verlangten die *l*-Taste.

Die anderen Kombinationen waren *antwortinkongruent*, beide Stimuluskategorien

erforderten unterschiedliche Antworten.

     Wir stellten die Hypothese auf, dass das neue Schema für die kombinierten

Kategorien insbesondere nach einem langen Intervall einen Gedächtnisvorteil entfaltet.

Frühere Forschung konnte zeigen, dass Informationen, die zu einem vorhandenen

Schema passen, besser erinnert werden und dass dieser Effekt über die Zeit zunimmt

(Hennies, Lambon Ralph, Kempkes, Cousins, & Lewis, 2016; van Kesteren, Rijpkema,

Ruiter, & Fernández, 2013). Der Effekt eines während einer Lernphase experimentell

induzierten Schemas wurde bisher aber noch nicht untersucht.

Die Resultate zeigten tatsächlich einen Gedächtnisvorteil für antwortkongruente

Stimuli nach der Konsolidierungsphase, während die unmittelbare Gedächtnisleistung

nicht variierte. Die Studie bietet erste Evidenz, dass während einer Lernphase durch die

Kombination von Stimuluskategorien ein neues Schema für die kongruenten Antworten

entstehen kann. Dieses Schema kann als vergängliches, kognitives Muster bezeichnet

werden. Diese Beschreibung passt bestens zur Definition von Bartlett (1935), der

Schemata als dynamische und sich ständig entwickelnde Muster beschrieb, die durch eine

laufende Aktivität *online* gebildet werden können.

Allgemeine Diskussion

Unsere Studien zeigen, dass verschiedene kognitive Konflikt während der

Kodierung die nachfolgende Gedächtnisleistung unterschiedlich beeinflussen können.

Zusammenfassend spielen die Aufmerksamkeitslenkung und Faktoren, die diese

beeinflussen, eine kritische Rolle. In der Tabelle 2 befindet sich eine Übersicht über die

Konflikte und deren Effekte. Im Folgenden sollen unsere Befunde in Bezug zu kognitiven

Theorien und neuropsychologischen Modellen gesetzt werden.

Konfliktmonitoring-Modell. Gemäss dem Konfliktmonitoring-Modell beinhaltet

das kognitive Kontrollsystem zwei dissoziierbare Komponenten, die eine regulative

Feedback-Schleife bilden (Botvinick et al., 2001; Egner & Hirsch, 2005; MacDonald et

al., 2000; Miller & Cohen, 2001). Die Konflikt überwachende, evaluative Komponente

ist mit dem ACC assoziiert, die regulierenden Komponente ist mit dem DLPFC

assoziiert. Die Befunde unserer Studien und früherer Forschung lassen den Schluss zu,

dass die Involvierung dieser beiden Komponenten während des Kodierens zu
unterschiedlichen Auswirkungen auf das Gedächtnis führen. Kognitive Konflikte durch
Aufgabenwechsel oder geteilter Aufmerksamkeit sind vor allem mit erhöhter Aktivität im
DLPFC assoziiert (Niendam et al., 2012; Reynolds et al., 2004). Der zusätzliche Bedarf
an kognitiver Kontrolle resultiert in einer reduzierten Aufmerksamkeitsfokussierung auf
den Zielstimulus, was die Gedächtnisleistung verschlechtert. Wird hingegen im ACC ein
Konflikt durch konkurrierende Antwortalternativen entdeckt, wird *top-down-*
Aufmerksamkeit rekrutiert und direkt auf den Zielreiz gelenkt, wobei die
aufgabenrelevanten Stimuluseigenschaften neuronal verstärkt werden (Botvinick et al.,
2001; Corbetta et al., 1991; Egner & Hirsch, 2005). Diese Aufmerksamkeitsallokation
kann sich in einem Gedächtnisvorteil manifestieren.

     In unserer zweiten Studie konnten wir diese gegenläufigen, unabhängigen Effekte
zeigen. Die mit dem DLPFC assoziierten Aufgabenwechsel führten zu einer schlechteren,
der mit einer ACC-Aktivierung assoziierte Antwortkategorie-Konflikt zu einer besseren
Abrufleistung und die beiden Effekte zeigten keine Interaktion. Eine bildgebende Studie,
in der Task-Switching mit einem Stroop-Konflikt kombiniert wurden, zeigte diese
doppelte Dissoziation ebenfalls (MacDonald et al., 2000). Aufgabenwechsel gingen mit
erhöhter DLPFC-Aktivierung und gleicher ACC-Aktivierung einher, Antwortkonflikte in
inkongruenten Stroop-Trials hingegen mit erhöhter ACC-Aktivierung und konstanter
DLPFC-Aktivierung.

     Load-Theorie. Gemäss der Load-Theorie von Lavie (2005) bestimmen der
perzeptuelle und der kognitive *Load*, wie visuelle Informationen kodiert werden. Ein
hoher perzeptueller Load wird durch eine steigende Anzahl verschiedener Items oder

deren Komplexität verursacht (Lavie, Lin, Zokaei, & Thoma, 2009). Die Theorie postuliert, dass visuelle Information automatisch kodiert wird so lange Kapazität in der Perzeption besteht, unabhängig davon, ob sie relevant ist oder nicht. Eine weitere zentrale Aussage der Load-Theorie ist, dass höhere Anforderungen an die kognitive Kontrolle (*cognitive laod*) zu mehr Distraktor-Interferenz führen, da die Priorisierung von relevanter Information beeinträchtigt ist.

Die Vorhersage für Aufgabenwechsel wäre daher, dass in den kognitiv anspruchsvolleren Switch-Trials durch eine mangelhafte Priorisierung von relevanter Information mehr Distraktoren kodiert werden als in Repeat-Trials. Genau diesen Effekt fanden wir in Experiment 1 unserer zweiten Studie, aus der Switch-Bedingung wurden deutlich mehr Distraktoren abgerufen als aus der Repeat-Bedingung. Aus Repeat-Trials wurden hingegen mehr Zielstimuli abgerufen als aus Switch-Trials, die Fokussierung war ungestört. Dieser Effekt scheint robust und wurde auch in anderen Studien gefunden (Chiu & Egner, 2016; Richter & Yeung, 2012, 2015). Die Befunde lassen den Schluss zu, dass bei erhöhten Kontrollanforderungen die Menge an kodierter Information zwar gleich bleibt, dass aber relevante Information weniger gezielt kodiert werden kann.

Aus der Load-Theorie lassen sich auch Implikationen für perzeptuelle Konflikte ableiten. In einer Bedingung mit höherem Load, der aber die perzeptuelle Kapazität nicht überschreitet, wäre ein negativer Effekt für die Zielstimuli zu erwarten, da Distraktoren automatisch mitkodiert werden und Interferenz erzeugen. Im ersten Experiment unserer zweiten Studie war der perzeptuelle Load in der inkongruenten Bedingung (zwei verschiedene Wörter) höher als in der kongruenten (zwei identische Wörter). Die Resultate zeigten, dass gleich viele Wörter pro Bedingung abgerufen wurden, was

veranschaulicht, dass die visuelle Information automatisch kodiert wurde, da Kapazität bestand. In der inkongruenten Bedingung wurden aber weniger Zielwörter abgerufen, was das automatische Mitkodieren und die Interferenz durch Distraktoren reflektiert. Eine weitere Implikation für perzeptuelle Konflikte wäre, dass bei einem sehr hohen perzeptuellen Load visuelle Information nicht kodiert wird, da die Kapazität überschritten wurde. Diesen Effekt konnten Greene, Murphy und Januszewski (2017) zeigen, die Erinnerungsleistung für periphere Stimuli war unter sehr hohem perzeptuellen Load reduziert.

Perzeptuelle Konflikte sind in der Literatur nicht klar definiert, sie können sich auch auf andere Aspekte beziehen als auf den perzeptuellen Load. Es wurden auch Gedächtnisvorteile durch perzeptuelle Konflikte beschrieben, so durch verschwommene Schriftbilder (Rosner, Davis et al., 2015), durch schwer leserliche Schriften (Diemand-Yauman, Oppenheimer, & Vaughan, 2011) oder durch auf dem Kopf stehende Wörter (Sungkhasettee, Friedman, & Castel, 2011). Die positiven Effekte dieser in der Literatur auch als *desirable difficulties* bezeichneten Kodierbedingungen basieren vor allem darauf, dass sie Prozesse auslösen können, die Lernen und Gedächtnis durch mehr Effort, andere Strategien und möglicherweise auch mehr Zeit verbessern können (Bjork & Bjork, 1992). In diesen Studien werden die Vpn zudem instruiert, das entsprechende Material zu lernen und zu erinnern, was ebenfalls Implikationen auf den Umgang mit dem Konflikt haben kann.

Unsere dritte Studie offenbarte, dass sich Effekte auf das Gedächtnis nach einem langen Intervall stark verändern können (Muhmenthaler & Meier, submitted). Antwortkongruente Stimuli wurden in einer unmittelbaren Testung gleich gut

wiedererkannt wie antwortinkongruente Stimuli, nach einer Woche zeigte sich aber ein

Gedächtnisvorteil für diese Stimuli. Ausserdem verschwand der sonst robuste negative

Effekt von Task-Switching auf die Gedächtnisleistung. Dies weist auf die Wichtigkeit

von Konsolidierungsprozessen hin. Bildgebende Studien zeigten, dass während der

Kodierung, Konsolidierung sowie beim Abruf von schema-kongruenten Inhalten der

mPFC aktiver ist als bei inkongruenten Inhalten (Bonasia et al., 2018; Spalding, Jones,

Duff, Tranel, & Warren, 2015; van Kesteren, Fernández, Norris, & Hermans, 2010;

Zeithamova, Dominick, & Preston, 2012). Bestehende Schemata scheinen demnach eine

Verlagerung der Gedächtnisbildung vom MTL zum mPFC zu bewirken, wo die Inhalte

durch den neuronalen Replay in kortikalen Regionen verstärkt und schnell in bestehende

Wissensstrukturen integriert werden (van Kesteren, Beul et al., 2013). Obwohl wir keine

direkte Evidenz haben, kann davon ausgegangen werden, dass die Konsolidierung des

neuen Schemas für antwortkongruenten Stimuli auf diesen Prozessen beruht. Das neue

Schema musste sich zuerst aber bilden. Die Schemabildung lässt sich mit einem Modell

von Lewis und Durrant (2011) erklären. Gemäss diesem entsteht ein neues Schema durch

einen wiederholten, überlappenden Replay für die kongruenten Inhalte während dem

Tiefschlaf. Die gemeinsamen Bereiche der simultan abgespielten Erinnerungen werden

durch höhere Feuerraten verstärkt, was zur graduellen Bildung eines Schemas führt. Es

wäre denkbar, dass neue Schemata während dem Tiefschlaf früh in der Nacht gebildet

werden und später in der Nacht während dem REM-Schlaf in das neokortikale Netzwerk

integriert werden (Durrant et al., 2015; Stickgold, Whidbee, Schirmer, Patel, & Hobson,

2000).

Mit unseren drei Studien und dieser Integrationsarbeit wurde ein Beitrag geleistet, die Auswirkungen unterschiedlicher Konflikte auf das Gedächtnis zu erklären und in weiteren Studien vorhersagen zu können. Die Befunde zeigen insgesamt, dass kognitive Konflikte eher mit Gedächtniseinbussen assoziiert sind. Ein Sonderstatus scheint Stimuli zuzukommen, die einen Antwortkonflikt auslösen, diese können das Gedächtnis verbessern. Eine effiziente Aufmerksamkeitsallokation scheint also ausschlaggebend für die spätere Gedächtnisleistung. Während die Aufmerksamkeitsfokussierung durch die meisten Konflikte beeinträchtigt wird, resultieren Antwortkonflikts in einer verstärkten Aufmerksamkeitsfokussierung auf den Zielstimulus, was den Gedächtnisvorteil erklären kann. Ungeklärt bleibt aber, wie sich einige Konflikte auf das konsolidierte Gedächtnis auswirken würden. Um Aussagen über kognitive Konflikte und Gedächtnis ausserhalb des Labors zu machen, wären deren Effekte nach einem längeren Intervall sicherlich relevant. Daher sollten in zukünftiger Forschung vermehrt längere Intervalle zwischen Lern- und Testphase angewendet werden.

Danksagung

References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the
    dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Conscious and
    nonconscious information processing: Attention and performance XV* (pp. 421–452).
    Cambridge, MA: MIT Press.

Atkinson, R. C., Hertmann, D. J., & Wescourt, K. T. (1974). Search processes in
    recognition memory. In R. L. Solso (Ed.), *Theories in cognitive psychology: The
    Loyola symposium* (pp. 101–146). Potomac, MD: Erlbaum.

Baddeley, A. D., & Della Sala, S. (1996). Working memory and executive control.
    *Philosophical Transactions of the Royal Society of London. Series B: Biological
    Sciences*, *351*(1346), 1397–1404.

Barch, D. M., Braver, T. S., Sabb, F. W., & Noll, D. C. (2000). Anterior cingulate and the
    monitoring of response conflict: Evidence from an fMRI study of overt verb
    generation. *Journal of Cognitive Neuroscience, 12*(2), 298–309.

Bartlett, F. C. (1935). Remembering. *Scientia, 52,* 221-226.

Becker, M. W., & Rasmussen, I. P. (2008). Guidance of attention to objects and locations
    by long-term memory of natural scenes. *Journal of Experimental Psychology:
    Learning, Memory, and Cognition, 34,* 1325–1338.

Bench, C., Frith, C. D., Grasby, P. M., Friston, K. J., Paulesu, E., Frackowiak, R. S. J., &
    Dolan, R. J. (1993). Investigations of the functional anatomy of attention using the
    Stroop test. *Neuropsychologia*, *31*(9), 907-922.

Bjork, R. A., & Bjork, E. L. (1992). *A new theory of disuse and an old theory of stimulus
    fluctuation.* In A. F. Healy, S. M. Kosslyn, & R. M. Shiffrin (Eds.), Essays in honor

of William K. Estes, Vol. 1. From learning theory to connectionist theory; Vol. 2. From learning processes to cognitive processes (pp. 35–67). Hillsdale, NJ: Erlbaum.

Bonasia, K., Sekeres, M. J., Gilboa, A., Grady, C. L., Winocur, G., & Moscovitch, M. (2018). Prior knowledge modulates the neural substrates of encoding and retrieving naturalistic events at short and long delays. *Neurobiology of Learning and Memory, 153,* 26–39.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624-652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in Cognitive Sciences*, *8*(12), 539–546. doi:10.1016/J.TICS.2004.10.003

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulated cortex. *Nature, 402,* 179–181.

Boyce, R., Glasgow, S. D., Williams, S., & Adamantidis, A. (2016). Causal evidence for the role of REM sleep theta rhythm in contextual memory consolidation. *Science*, *352*(6287), 812–816.

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural Mechanisms of Transient and Sustained Cognitive Control during Task Switching. *Neuron*, *39*(4), 713–726. doi :10.1016/S0896-6273(03)00466-5

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science, 280,* 747–749. doi:10.1126/science.280.5364.747

Castel, A. D., & Craik, F. I. (2003). The effects of aging and divided attention on

memory for item and associative information. *Psychology and aging*, *18*(4), 873-

885. doi:10.1037/0882-7974.18.4.873

Chiu, Y. C., & Egner, T. (2016). Distractor-relevance determines whether task-switching

enhances or impairs distractor memory. *Journal of Experimental Psychology:*

Human Perception and Performance, 42(1*)*, 1-5. doi:10.1037/xhp0000181

Chun, M. M., & Turk-Browne, N. B. (2007). Interactions between attention and memory.

Current Opinion in Neurobiology, *17*(2), 177–184.

Cohen, J. D., Braver, T. S., & O'Reilly, R. (1996). A computational approach to

prefrontal cortex, cognitive control and schizophrenia: recent developments and

current challenges. *Philosophical Transactions of the Royal Society of London.*

Series B: Biological Sciences, 351(1346), 1515–1527.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic

processes: a parallel distributed processing account of the Stroop effect.

Psychological Review, *97*(3), 332.

Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1991).

Selective and divided attention during visual discriminations of shape, color, and

speed: functional anatomy by positron emission tomography. *Journal of*

Neuroscience, *11*(8), 2383-2402.

Craik, F. I., Govoni, R., Naveh-Benjamin, M., & Anderson, N. D. (1996). The effects of

divided attention on encoding and retrieval processes in human memory. *Journal of*

Experimental Psychology: General, 125, 159–180.

Craik, F. I., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*(3), 474.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective attention. *Annual Review of Neuroscience, 18,* 193-222.

Diekelmann, S., & Born, J. (2007). One memory, two ways to consolidate? *Nature Neuroscience*, *10*(9), 1085. https://www.nature.com/articles/nn0907-1085

Diemand-Yauman, C., Oppenheimer, D. M., & Vaughan, E. B. (2011). Fortune favors the **bold** and the *italicized*: Effects of disfluency on educational outcomes. *Cognition*, *118*(1), 111–115. doi:10.1016/J.COGNITION.2010.09.012

Dreisbach, G., & Wenke, D. (2011). The shielding function of task sets and its relaxation during task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 1540–1546. doi:10.1037/a0024077

Dudai, Y., Karni, A., & Born, J. (2015). The consolidation and transformation of memory. *Neuron, 88*(1), 20–32. doi:10.1016/j.neuron.2015.09.004

Dudai, Y., & Morris, R. G. (2013). Memorable trends. *Neuron*, *80*(3), 742-750. doi:10.1016/j.neuron.2013.09.039

Durrant, S. J., Cairney, S. A., McDermott, C., & Lewis, P. A. (2015). Schema-conformant memories are preferentially consolidated during REM sleep. *Neurobiology of Learning and Memory*. doi.org/10.1016/j.nlm.2015.02.011

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 380–390.

Egner, T. (2017). Conflict adaptation: Past, present, and future of the congruency

    sequence effect as an index of cognitive control. In T. Egner (Ed.). *The Wiley*

    handbook of cognitive control (pp. 64–78). Oxford: Wiley-Blackwell.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through

    cortical amplification of task-relevant information. *Nature Neuroscience*, *8*(12),

    1784–1790. doi:10.1038/nn1594

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of

    a target letter in a nonsearch task. *Percept. Psychophys. 16,* 143–149.

Gardiner, J. M., & Parkin, A. J. (1990). Attention and recollective experience in

    recognition memory. *Memory & Cognition, 18,* 579–583.

Gilboa, A., & Marlatte, H. (2017). Neurobiology of Schemas and Schema-Mediated

    Memory. Trends in Cognitive Sciences, 21(8), 618–631.

    doi:10.1016/j.tics.2017.04.013

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information:

    Strategic control of activation of responses. *Journal of Experimental Psychology:*

    General, 4, 480-506.

Greene, C. M., Murphy, G., & Januszewski, J. (2017). Under high perceptual load,

    observers look but do not see. *Applied Cognitive Psychology, 31*(4), 431–437.

Hennies, N., Lambon Ralph., M. A., Kempkes, M., Cousins, J. N., & Lewis, P. A. (2016).

    Sleep spindle density predicts the effect of prior knowledge on memory

    consolidation. *The Journal of Neuroscience, 36(*13), 3799–3810.

    doi:10.1523/JNEUROSCI.3162-15.2016

Jersild, A. T. (1927). Mental set and shift. *Archives of psychology, whole nr. 89.*

Kerns, J. G. (2006). Anterior cingulate and prefrontal cortex activity in an FMRI study of trial-to-trial adjustments on the Simon task. *NeuroImage, 33*(1), 399–405. doi:10.1016/J.NEUROIMAGE.2006.06.012

Kiehl, K. A., Liddle, P. F., & Hopfinger, J. B. (2000). Error processing and the rostral anterior cingulate: an event-related fMRI study. *Psychophysiology, 37,* 216–223.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching - a review. *Psychological Bulletin, 136*(5), 849–874. doi:10.1037/a0019842

Kim, C., Cilles, S. E., Johnson, N. F., & Gold, B. T. (2012). Domain general and domain preferential brain regions associated with different types of task switching: A meta-analysis. *Human brain mapping*, *33*(1), 130-142.

Kim, S., & Cho, Y. S. (2014). Congruency sequence effect without feature integration and contingency learning. *Acta Psychologica*, *149*, 60–68.

Kimberg, D. Y., Aguirre, G. K., & D'Esposito, M. (2000). Modulation of task-related neural activity in task-switching: an fMRI study. *Cognitive Brain Research*, *10*(1-2), 189-196.

Krebs, R. M., Boehler, C. N., De Belder, M., & Egner, T. (2015). Neural conflict-control mechanisms improve memory for target stimuli. *Cerebral Cortex,* (3):833-43. doi:10.1093/cercor/bht283

Kumaran, D., Hassabis, D., & McClelland, J. L. (2016). What Learning Systems do Intelligent Agents Need? Complementary Learning Systems Theory Updated. *Trends in Cognitive Sciences, 20*(7), 512–534. doi:10.1016/J.TICS.2016.05.004

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9*(2), 75–82. doi:10.1016/j.tics.2004.12.004.

Lavie, N., Lin, Z., Zokaei, N., & Thoma, V. (2009). The role of perceptual load in object recognition. *Journal of Experimental Psychology: Human Perception and Performance, 35*(5), 1346-1358. doi:10.1037/a0016454

Lewis, P. A., & Durrant, S. J. (2011). Overlapping memory replay during sleep builds cognitive schemata. *Trends in Cognitive Sciences*, *15*(8), 343-351.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*(5472), 1835–1838.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychological Bulletin, 109*, 163–203.

McClelland, J. L. (2013). Incorporating rapid neocortical learning of new schema-consistent information into complementary learning systems theory. *Journal of Experimental Psychology: General*, *142*(4), 1190.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review*, *102*(3), 419–457. https://doi.org/10.1037/0033-295X.102.3.419

Meier, B., Woodward, T. S., Rey-Mermet, A., & Graf, P. (2009). The bivalency effect in task switching: General and enduring. *Canadian Journal of Experimental*

Psychology/Revue canadienne de psychologie expérimentale, *63*(3), 201-210.

doi:10.1037/a0014311

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance.

Journal of Experimental Psychology: Learning, Memory, and Cognition, 22 (6),

1423-1442.

Meiran, N. (2008). The dual implication of dual affordance: Stimulus-task binding and

attentional focus of changing during task preparation. *Experimental Psychology, 55*,

251–259.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function.

Annual Review of Neuroscience, *24*(1), 167–202.

Muhmenthaler, M. C., & Meier, B. (2019a). Task switching hurts memory encoding.

Experimental Psychology, 66(01), 58-67. doi:10.1027/1618-3169/a000431

Muhmenthaler, M. C., & Meier, B. (2019b). Different impact of task switching and

response-category conflict on subsequent memory. *Psychological Review*.

doi:10.1007/s00426-019-01274-3

Muhmenthaler, M. C., & Meier, B. (submitted). Response congruency affect delayed

memory performance.

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S.

(2012). Meta-analytic evidence for a superordinate cognitive control network

subserving diverse executive functions. *Cognitive, Affective, & Behavioral*

Neuroscience, 12(2), 241–268. doi:10.3758/s13415-011-0083-5

Nishida, M., Pearsall, J., Buckner, R. L., & Walker, M. P. (2008). REM sleep, prefrontal theta, and the consolidation of human emotional memory. *Cerebral Cortex*, *19*(5), 1158-1166.

Norman, D. A., & Shallice, T. (1986). Attention to action. In *Consciousness and self-regulation* (pp. 1–18). Springer.

Ortiz-Tudela, J., Milliken, B., Botta, F., LaPointe, M., & Lupiañez, J. (2017). A cow on the prairie vs. a cow on the street: long-term consequences of semantic conflict on episodic encoding. *Psychological Research*, *81*(6), 1264–1275. doi:10.1007/s00426-016-0805-y

Pardo, J. V., Pardo, P. J., Janer, K. W., & Raichle, M. E. (1990). The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proceedings of the National Academy of Sciences*, *87*(1), 256–259.

Piaget, J. (1952). The origins of intelligence in children (Vol. 8), International Universities Press.

Rey-Mermet, A., & Meier, B. (2014). More conflict does not trigger more adjustment of cognitive control for subsequent events: A study of the bivalency effect. *Acta Psychologica*, *145*, 111–117. doi:10.1016/j.actpsy.2013.11.005

Rey-Mermet, A., & Meier, B. (2017). Post-conflict slowing after incongruent stimuli: From general to conflict-specific. *Psychological Research*, *81*(3), 611-628. doi:10.1007/s00426-016-0767-0

Reynolds, J. R., Donaldson, D. I., Wagner, A. D., & Braver, T. S. (2004). Item- and task-level processes in the left inferior prefrontal cortex: Positive and negative correlates

of encoding. *NeuroImage, 21*, 1472–1483. doi:10.1016/j.neuroimage.2003.10.033

doi:10.1016/J.NEUROIMAGE.2003.10.033

Richter, F. R., & Yeung, N. (2012). Memory and cognitive control in task switching.

Psychological Science, 23, 1256–1263. doi:10.1177/0956797612444613

Richter, F. R., & Yeung, N. (2015). Corresponding influences of top-down control on

task switching and long-term memory. *The Quarterly Journal of Experimental*

Psychology, 68, 1124-1147. doi:10.1080/17470218.2014.976579

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple

cognitive tasks. *Journal of Experimental Psychology: General, 124*(2), 207-231.

Rosner, T. M., D'Angelo, M. C., MacLellan, E., & Milliken, B. (2015). Selective

attention and recognition: effects of congruence on episodic learning. *Psychological*

Research, 79(3), 411-424. doi:10.1007/s00426-014-0572-6

Rosner, T. M., Davis, H., & Milliken, B. (2015). Perceptual blurring and recognition

memory: a desirable difficulty effect revealed. *Acta Psychologica, 160,* 11-22.

doi:10.1016/j.actpsy.2015.06.006

Rumelhart, D. E. (1984). Schemata and the cognitive system. In R. S. Wyer & T. K.Srull,

Handbook of social cognition(pp. 161–188). Hillsdale, NJ: Lawrence Erlbaum.

Sakai, K. (2008). Task set and prefrontal cortex. *Annu. Rev. Neurosci.*, *31*, 219-245.

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal

lesions. *Journal of Neurol Neurosurg Psychiatry, 20*, 11–21.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information

processing: II. Perceptual learning, automatic attending, and a general theory.

Psychological Review, 84, 127-190.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information
processing. In R.W. Proctor, & T.G. Reeve (Eds.), *Stimulus-response compatibility:
an integrated perspective* (pp. 31-86). Amsterdam: Elsevier science.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes.
Science, 283, 1657e1661.

Spalding, K. N., Jones, S. H., Duff, M. C., Tranel, D., & Warren, D. E. (2015).
Investigating the neural correlates of schemas: Ventromedial prefrontal cortex is
necessary for normal schematic influence on memory. *Journal of Neuroscience,
35*(47), 15746–15751. doi:10.1523/JNEUROSCI.2767-15.2015

Squire, L. R., Genzel, L., Wixted, J. T., & Morris, R. G. (2015). Memory consolidation.
Cold Spring Harbor Perspectives in Biology, *7*(8), 1-21.

Stickgold, R. (2005). Sleep-dependent memory consolidation. *Nature, 437*(7063), 1272–
1278. https://doi.org/10.1038/nature04286

Stickgold, R., Whidbee, D., Schirmer, B., Patel, V., & Hobson, J. A. (2000). Visual
discrimination task improvement: A multi-step process occurring during sleep.
Journal of Cognitive Neuroscience, 12(2), 246–54. doi:10.1162/089892900562075

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of
Experimental Psychology,*18, 643–62

Sungkhasettee, V. W., Friedman, M. C., & Castel, A. D. (2011). Memory and
metamemory for inverted words: Illusions of competency and desirable difficulties.
Psychonomic Bulletin & Review, *18*(5), 973. doi:10.3758/s13423-011-0114-9

Tse, D., Langston, R. F., Kakeyama, M., Bethus, I., Spooner, P. A., Wood, E. R., …
Morris, R. (2007). Schemas and memory consolidation. *Science, 316,* 76–82.

Tse, D., Takeuchi, T., Kakeyama, M., Kajii, Y., Okuno, H., Tohyama, C., … Morris, R.

(2011). Schema-dependent gene activation and memory encoding in neocortex.

Science (New York, N.Y.), 333(6044), 891–895. doi:10.1126/science.1205274

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology/Psychologie

canadienne*, *26*(1), 1.

van Kesteren, M. T. R., Beul, S. F., Takashima, A., Henson, R. N., Ruiter, D. J., &

Fernández, G. (2013). Differential roles for medial prefrontal and medial temporal

cortices in schema-dependent encoding: From congruent to incongruent.

Neuropsychologia, *51*(12), 2352–2359.

van Kesteren, M. T. R., Fernández, G., Norris, D. G., & Hermans, E. J. (2010). Persistent

schema-dependent hippocampal-neocortical connectivity during memory encoding

and postencoding rest in humans. *Proceedings of the National Academy of Sciences

of the United States of America 107*, 7550–

7555.doi:10.1016/J.NEUROPSYCHOLOGIA.2013.05.027

van Kesteren, M. T. R., Rijpkema, M., Ruiter, D. J., & Fernández, G. (2013).

Consolidation differentially modulates schema effects on memory for items and

associations. *PloS One*, *8*(2), e56155. doi:10.1371/journal.pone.0056155

van Kesteren, M. T. R., Ruiter, D. J., Fernández, G., & Henson, R. N. (2012). How

schema and novelty augment memory formation. *Trends in Neurosciences*, *35*(4),

211–219. doi:10.1016/J.TINS.2012.02.001

Verguts, T., Notebaert, W., Kunde, W., & Wühr, P. (2011). Post-conflict slowing:

cognitive adaptation after conflict processing. *Psychonomic Bulletin & Review*,

18(1), 76–82.

Wais, P. E., Rubens, M. T., Boccanfuso, J., & Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *Journal of Neuroscience, 30,* 8541–8550.

Wang, S. H., & Morris, R. G. M. (2010). Hippocampal-neocortical interactions in memory formation, consolidation, and reconsolidation. *Annual Review of Psychology, 61*(1), 49–79. doi:10.1146/annurev.psych.093008.100523

Woodward, T. S., Meier, B., Tipper, C., & Graf, P. (2003). Bivalency is costly: Bivalent stimuli elicit cautious responding. *Experimental Psychology*, *50*(4), 233. doi:10.1027//1618-3169.50.4.233

Yeung, N. (2013). *Conflict monitoring and cognitive control.* Oxford handbook of cognitive neuroscience.

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: conflict monitoring and the error-related negativity. *Psychological Review*, *111*(4), 931-959.

Yeung, N., Nystrom, L. E., Aronson, J. A., & Cohen, J. D. (2006). Between-task competition and cognitive control in task switching. *Journal of Neuroscience, 26*(5), 1429–1438. doi:10.1523/JNEUROSCI.3109-05.2006

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46*(3), 441–517. doi:10.1006/jmla.2002.2864

Zeithamova, D., Dominick, A. L., & Preston, A. R. (2012). Hippocampal and ventral medial prefrontal activation during retrieval-mediated learning supports novel inference. *Neuron, 75*(1), 168–179. doi:10.1016/j.neuron.2012.05.010

Tabelle 1.

Überblick über die Aufgaben, Stimuli, Antworten und Forschungsfragen der drei Studien

Studie	Aufgaben	Stimuli	Antworten	Forschungsfrage
Muhmenthaler & Meier (2019) Experiment 1	*Tierurteil:* Vogel vs. Säugetier *Objekturteil*: Musikinstrument vs. Küchenutensil	Wörter (visuell) und Farbfotos, 20 pro Kategorie	*a*: Säugetier / Musikinstrument *l*: Vogel / Küchenutensil	Aufgabenwechsel auf Rekognitions- Leistung
Experiment 2	*Grössenurteil:* grösser vs. kleiner als Fussball *Belebturteil*: belebt vs. nicht belebt	Farbfotos, 16 pro Kategorie	*a*: grösser als Ball / lebend *l*: kleiner als Ball, nicht lebend	
Muhmenthaler & Meier (under review)	*Tierurteil:* Vogel vs. Säugetier *Objekturteil*: Musikinstrument vs. Küchenutensil	Verschachtelte Wort-Stimuli, 16 pro Kategorie	*a*: Säugetier / Musikinstrumente *l*-Taste: Vogel / Küchenutensil	Kombinierte Konflikte auf freien Abruf
Muhmenthaler & Meier (submitted)	Gleich wie Experiment 2 der ersten Studie			Antwortkongruenz Schemabildung Effekt von Konsolidierung

Tabelle 2.

Überblick Konflikte, Effekte auf das Gedächtnis und Referenzen

Konflikt	Effekt auf Gedächtnis	Referenzen
Antwort-Inkongruenz	Negativer Effekt (*nach Konsolidierung)*	Muhmenthaler & Meier (submitted)
Antwortkategorie-Konflikt	Positiver Effekt	Krebs et al., 2015; Rosner, D'Angelo et al., 2015
		Muhmenthaler & Meier, 2019b; Experimente 2/3
Bivalenz	Negativer Effekt	Muhmenthaler & Meier (2019a)
Geteilte Aufmerksamkeit	Negativer Effekt	Castel & Craik (2003), Craik et al., (1996)
Perzeptueller Konflikt	Beide Richtungen möglich	Muhmenthaler & Meier (2019b); Experiment. 1
	Nicht klar definiert	Greene et al., 2017
		Diemand-Yauman et al., 2011
Schema-Inkongruenz	Negativer Effekt	Hennies et al., 2016; van Kesteren, Rijpkema et al., 2013
Stimuluskategorie-Konflikt	Kein Effekt (Kontrollbedingung)	Muhmenthaler & Meier (2019b), Experiment 4
Task-Switching	Negativer Effekt auf Targets	Richter & Yeung, 2012, 2015; Reynolds et al., 2004
		Muhmenthaler & Meier (2019b)

Task Switching Hurts Memory Encoding

Michèle C. Muhmenthaler and Beat Meier ⓘD

Institute of Psychology, University of Bern, Switzerland

Abstract: Research consistently shows that task switching slows down performance on switch compared to repeat trials, but the consequences on memory are less clear. In the present study, we investigated the impact of task switching on subsequent memory performance. Participants had to switch between two semantic classification tasks. In Experiment 1, the stimuli were univalent; in Experiment 2, the stimuli were bivalent (relevant for both tasks). The aim was to disentangle the conflicts triggered by task switching and bivalency. In both experiments, recognition memory for switch and repeat stimuli was tested subsequently. During encoding, task switching produced switch costs. Critically, subsequent memory was lower for switch compared to repeat stimuli in both experiments, and this effect was increased in Experiment 2 with bivalent material. We suggest that the requirement to switch tasks hurts the encoding of task-relevant information and thus impairs subsequent memory performance.

Keywords: cognitive control, memory, univalent stimuli, bivalent stimuli, response compatibility, memory selectivity

With the beginning of the industrial world, it was a major issue to find the most efficient way to execute work procedure. According to Taylorism, the parsing of a procedure into small parts and the repetition of those small elements by eliminating all unnecessary movements was this "one best way" (Kanigel, 2005). However, in order to specify how goal-directed behavior is implemented, in the quest to understand cognitive processing, Miller, Galanter, and Pribam (1960) suggested a "test-operate-test-exit" (TOTE) unit, which, by definition, includes task switches as an optimal way to efficient performance. While successful performance necessarily requires flexibility, investigating the consequences of switching tasks on memory has just begun. In laboratory situations, such behavior is typically explored with the task-switching paradigm (e.g., Allport, Styles, & Hsieh, 1994; Jersild, 1927; Rogers & Monsell, 1995). The main goal of the present study was to investigate how task switching affects subsequent memory performance.

Cognitive control refers to the ability to form a plan, to maintain it in face of distraction, and to adjust behavior appropriately in case of cognitive conflict (Norman & Shallice, 1986; Posner & Snyder, 1975; Botvinick, Braver, Barch, Carter, & Cohen, 2001). Task switching is a typical example in which cognitive control is necessary. The increase in cognitive control associated with the requirement to switch

between two tasks usually results in slower and less accurate performance compared to repeating the same task (e.g., Rogers & Monsell, 1995). The conflict produced by task switching is assumed to reflect the involvement of endogenous control processes that are needed to reconfigure the task set (Vandierendonck, Liefooghe, & Verbruggen, 2010; Rogers & Monsell, 1995). The requirement for cognitive control is further enhanced when the material involves bivalent stimuli, that is, stimuli that can be used to perform both tasks rather than univalent stimuli. For example, if one task requires participants to classify animals as birds or mammals and the other task requires participants to classify objects as musical instruments or kitchen utensils, a sparrow would be a *univalent* stimulus because it can only be used for the animal task but not for the object task. In contrast, if one task requires participants to classify a stimulus by size (e.g., as bigger or smaller than a soccer ball) and the other task requires participants to classify a stimulus by animacy (i.e., as living or non-living), a sparrow would be a *bivalent* stimulus because it can be used for both, the size and the animacy task. Bivalent stimuli create an additional conflict because they not only require to switch task, but also to select which task to perform (Allport et al., 1994; Woodward, Meier, Tipper, & Graf, 2003). Responding to bivalent stimuli causes slower reaction times compared to responding to univalent stimuli and even leads to long-lasting slowing on subsequent performance (i.e., the "bivalency effect," Meier, Woodward, Rey-Mermet, & Graf, 2009; Woodward et al., 2003). Both types of conflicts – task switching and bivalency – contribute to "switch costs" as

they both slow down reaction times and increase error rates (Jersild, 1927; Rogers & Monsell, 1995). However, as most task-switching experiments involve bivalent stimuli, the effects of switching and bivalency on switch costs are typically confounded. By using one experiment with univalent stimuli and one experiment with bivalent stimuli, we aimed to assess the separate impact of task switching and bivalency on subsequent memory performance in the present study.

So far, only a few studies have examined the effect of task switching on memory and all of them used bivalent stimuli. Reynolds, Donaldson, Wagner, and Braver (2004) investigated encoding processes during switching and repeating a task. In the study phase, participants performed two semantic classification tasks with single words. In two blocks, they performed one of the tasks alone (single-task condition), and in one block, they switched between the two tasks (task-switching condition). In a subsequent memory test, more words from the single-task compared to the task-switching condition were recognized correctly. Thus, memory performance was lower when control demands were higher. More interestingly for the purpose of the present study, within the task-switching blocks, memory performance for repeat stimuli was better than for switch stimuli, suggesting not only a block-specific but also a trial-specific effect. Together, the higher cognitive demands associated with task switching reduced memory performance.

Richter and Yeung (2012) also investigated the effect of task switching on memory. They used compound stimuli consisting of pictures and words and participants had to switch between classifying them. Thus, each trial consisted of task-relevant (target) and task-irrelevant (distractor) information. The results showed that task switching compared to task repetition *impaired* memory performance for targets, but *improved* memory performance for distractors. The authors explained the latter with interference from previously active task sets (i.e., task-set inertia; Allport et al., 1994). Due to residual attention to the competing, now-irrelevant task, encoding of the distractor would be facilitated in switch trials (Yeung, Nystrom, Aronson, & Cohen, 2006). In contrast, attention toward task-relevant information was unimpeded in repeat trials, resulting in better encoding for targets in repeat compared to switch trials. In a follow-up study, Richter and Yeung (2015) replicated these results.

Chiu and Egner (2016) focused on task-irrelevant stimulus features by investigating two distractor categories. In one group, participants switched between two classification tasks, the distractors were relevant in one task and irrelevant in the competing task. In the other group, the distractors (objects in the background) were never task relevant. The results showed better memory for distractors which

were task relevant in one of the two tasks on switch compared to repeat trials, indicating that task-set inertia enhanced distractor encoding (Yeung et al., 2006). In the other condition with the truly irrelevant distractors, the results showed that memory for distractors was lower in switch than in repeat trials, indicating that the higher cognitive demands associated with task switching reduced encoding of completely irrelevant information (Jenkins, Lavie, & Driver, 2005).

Together, these findings suggest that task switching affects incidental memory performance. The interference associated with task switching results in less focused attention toward task-relevant information, leading to lower memory performance (Richter & Yeung, 2012, 2015). However, as all the previous studies have used bivalent stimuli, task switching and stimulus bivalency were confounded. In order to address the pure impact of task switching, we used univalent stimuli in Experiment 1 of the present study. Moreover, all the previous studies have used a task-cueing procedure in which a cue signals which task is to be performed such that switch and repeat trials appear in a random order (e.g., Shaffer, 1965). Task cueing requires the active maintenance of both task sets and may thus present additional attentional monitoring demands (Braver, Reynolds, & Donaldson, 2003). In contrast, in the present study, we used the alternating run paradigm in which switch and repeat trials appear in a predictable order (e.g., AABB) in order to reduce these demands (cf. Rogers & Monsell, 1995).

The Present Study

We present two task-switching experiments, one with univalent and one with bivalent stimuli. In the study phase of both experiments, participants had to switch between two semantic classification tasks. Then, a surprise memory test took place. We hypothesized that memory performance for switch trials would be lower than for repeat trials in both experiments (i.e., with univalent and bivalent stimuli) due to the higher control demands for task switching compared to task repetition. The enhanced cognitive demands impair target encoding by affecting stimulus-processing priorities (Lavie, Hirst, De Fockert, & Viding, 2004). In Experiment 2, we expected more interference in switch trials due to the additional requirement to counteract the between-task interference associated with bivalent stimuli (Allport & Wylie, 1999; Rey-Mermet & Meier, 2012) which has been shown to impair the encoding of task-relevant information (cf. Richter & Yeung, 2012, 2015).

In both experiments, we used the remember/know procedure to assess the contribution of recollection and familiarity to recognition memory performance (Tulving, 1985; Yonelinas, 2002). As switching task requires attention and

dividing attention reduces recollection (Yonelinas, 2002; Gardiner & Parkin, 1990), we expected that the difference between switch and repeat stimuli would be mainly expressed in remember responses.

Experiment 1

The aim of Experiment 1 was to test whether the conflict triggered by task switching affects subsequent recognition memory performance. Participants performed two different tasks (animal and object classification) in a regular AABB-order. For half of the participants, the stimuli were presented as words, and for the other half, they were presented as pictures. Importantly, all the stimuli were univalent.

Method

Participants
The participants were 80 volunteers (43 male and 37 female) from the general population, recruited by word of mouth, and all of them were German speaking with an age from 18 to 35 years ($M = 24.70$, $SD = 4.51$). The study was approved by the local ethical committee of the University of Bern; all participants gave written consent.

Material
For the condition with pictures, the material consisted of 160 photographs of easy to name stimuli. The pictures were collected from a web search. Half were animals (mammals or birds), and the other half were objects (musical instruments or kitchen utensils). The size of the photographs was approximately 300 × 300 pixels. For the condition with words, 160 words were used. They were typical exemplars of the same four categories and consisted of 3–10 letters. The words were displayed in black letters against a white background in Courier New font.[1]

The stimuli were divided into two lists of 80 pictures and words, respectively, and contained an equal number of stimuli of the four categories. One of the lists was used in the study phase, and both lists were presented in the test phase. The stimuli were counterbalanced across participants, so that each stimulus occurred equally often in the repeat and switch condition.

Procedure
One half of the participants were tested with words and the other half with pictures; they were randomly assigned to each condition and were tested individually in a computer laboratory. In the study phase, they were instructed to categorize the stimuli as quickly and correctly as possible. For animals, participants had to classify them as mammal or bird, and for objects, they had to classify them as musical instrument or kitchen utensil. The stimuli were presented randomized in the middle of the screen, each task twice in succession (see Figure 1). After a practice phase with 10 trials, participants performed the study phase with 80 trials. They responded on a standard computer keyboard using their index fingers. They had to press the *a*-key when the stimulus was either a mammal or a musical instrument and the *l*-key when the stimulus was either a bird or a kitchen utensil. The stimuli were presented until a response key was pressed, and then the next stimulus was presented after 200 ms of blank screen.
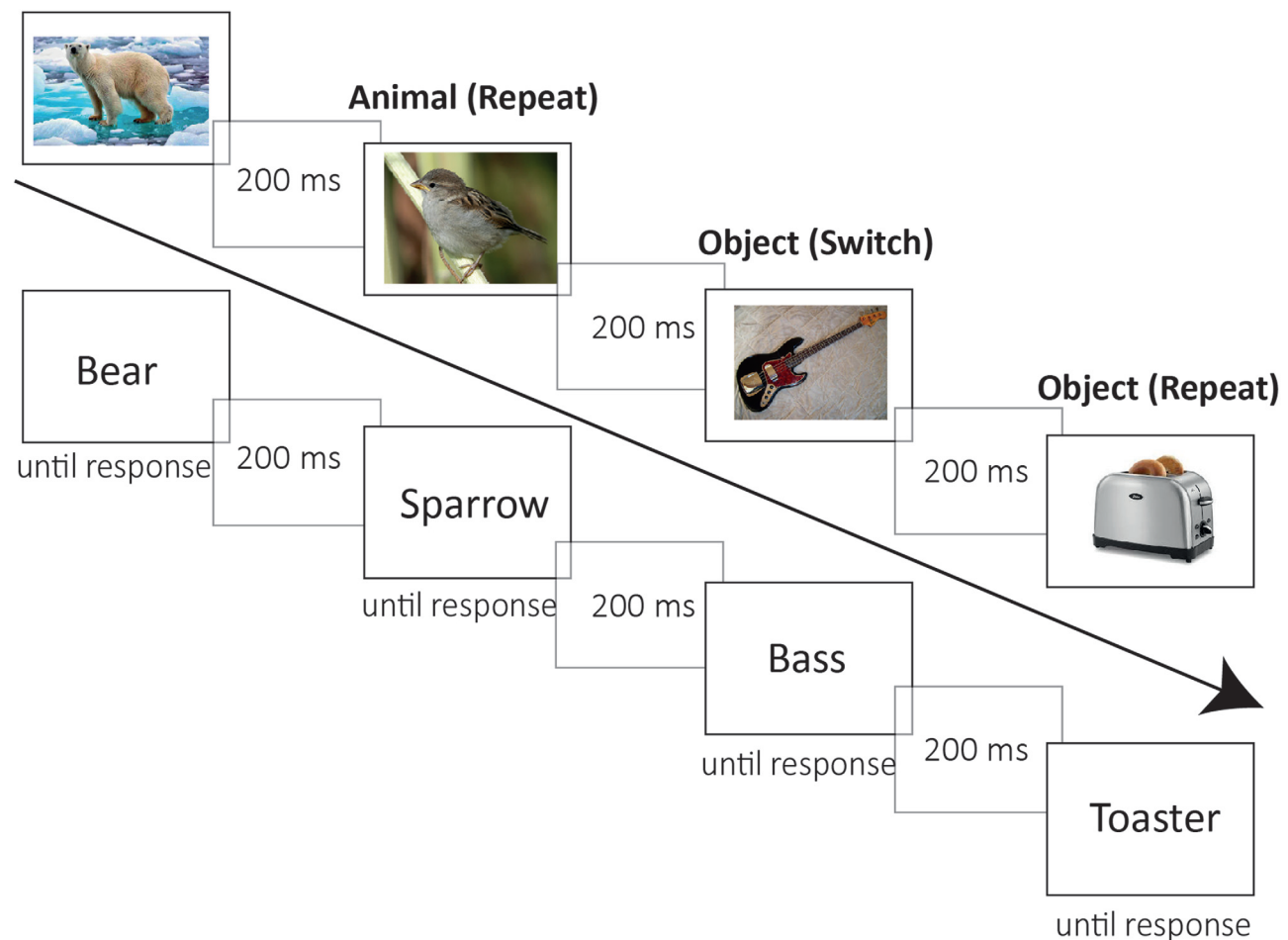
Following the study phase, participants had to complete a demanding reading span task (Daneman & Carpenter, 1980). The main purpose of this task was to create a filled retention interval between study and test phase. Participants had to read a series of two to six sentences. For each sentence, they had to indicate whether it was meaningful and they had to recall the last word of the sentence. Reading span was defined as the size of the largest set in which all words were correctly recalled in at least three of the five consecutive trials.

The third part of the experiment involved an incidental recognition memory test and an additional remember/know judgment (cf. Meier, Rey-Mermet, Rothen, & Graf, 2013). Participants had to indicate whether they had seen a stimulus already during the task-switching phase by pressing the *j*-key for "old" stimuli or not by pressing the *n*-key for "new" stimuli. In case of an "old"-response, they were required to give an additional remember/know judgment by pressing the *1*-key for "remember" or the *2*-key for "know" on the number pad. For each trial, the stimulus was presented in the middle of the screen until a response key was pressed. The stimuli appeared in randomized order with an interval of 200 ms. One half of the stimuli were old (presented in the study phase) and the other half new (unseen). The entire experiment lasted about 25 min. All raw data for Experiment 1 are listed in the Electronic Supplementary Material, ESM 1.

Analysis
For the study phase, mean reaction times and accuracy in the task-switching phase were analyzed separately using an analysis of variance (ANOVA) with the within-subject factor trial type (repeat vs. switch) and the between-subject factor material (words vs. pictures). For the test phase, the hit and the false alarms for each participant were

---

[1] Materials used to conduct the research (including analysis code) will be made available to other researchers for purposes of replicating the procedure or reproducing the results by email to the corresponding author.

Animal (Switch)

Animal (Repeat)

200 ms

Object (Switch)

200 ms

Bear

Object (Repeat)

until response   200 ms

200 ms

Sparrow

until response   200 ms

Bass

200 ms

Toaster

until response   200 ms

until response

Figure 1. Predictable AABB study trial sequence of Experiment 1.

computed. As it was not possible to assign the false alarm rates to the repeat or switch condition, we used hit rates only as recognition scores (cf. Ortiz-Tudela, Milliken, Botta, LaPointe, & Lupiañez, 2016). Memory performance was also analyzed with the within-subject factor trial type (repeat vs. switch) and the between-subject factor material (words vs. pictures). In addition, remember and know responses were analyzed separately. Reading span score was correlated with accuracy, reaction times, and the hit rate. We excluded one participant with an error rate > 30% in the study phase. An α level of .05 was used. Effect sizes are expressed as η_p^2 values.

Results

Study Phase

As expected, participants were faster to respond to repeat ($M = 1{,}110$ ms, $SE = 29$) than to switch trials ($M = 1{,}234$ ms, $SE = 37$), $F(1, 77) = 41.5$, $p < .001$, $\eta_p^2 = .35$. Overall, participants were faster to respond to pictures

($M = 970$ ms, $SE = 46$) than to words ($M = 1{,}375$ ms, $SE = 45$), $F(1, 77) = 39.6$, $p < .001$, $\eta_p^2 = .34$, but the interaction was not significant, $F(1, 77) = 0.37$, $p = .543$, $\eta_p^2 = .05$). The same ANOVA on the accuracy data revealed that performance was lower on switch ($M = 0.93$, $SE = 0.01$) than on repeat trials ($M = 0.95$, $SE = 0.01$), $F(1, 77) = 10.1$, $p = .002$, $\eta_p^2 = .12$. Accuracy was lower for words ($M = 0.92$, $SE = 0.01$) than for pictures ($M = 0.96$, $SE = 0.01$), $F(1, 77) = 16.3$, $p < .001$, $\eta_p^2 = .18$, but the interaction was not significant $F(1, 77) = 3.02$, $p = .086$, $\eta_p^2 = .04$, indicating that switch costs were not different for words and pictures. Together, our results showed typical switch costs.

Test Phase

Overall, the proportion of hits was $M = 0.71$, $SE = 0.14$, and the proportion of false alarms was $M = 0.23$, $SE = 0.13$. The ANOVA with the factors trial type and materials revealed that memory was significantly better for repeat ($M = 0.72$, $SE = 0.13$) than for switch trials ($M = 0.70$, $SE = 0.17$), $F(1, 77) = 6.8$, $p = .011$, $\eta_p^2 = .08$. Words and pictures did
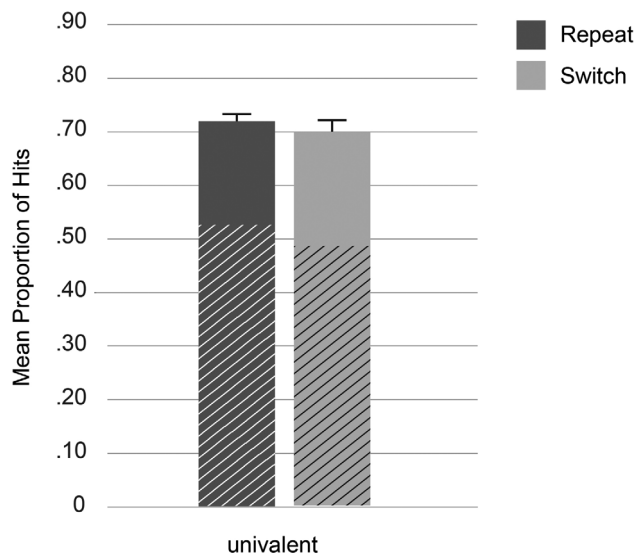
Figure 2. Memory performance in Experiment 1. Mean proportion of hits as a function of task switching with univalent stimuli. The shaded areas reflect *remember*; the solid areas represent *know* responses. Error bars represent standard errors.

not differ, $F(1, 77) = 1.74$, $p = .19$, $\eta_p^2 = .02$, and the interaction was not significant, $F(1, 77) = 1.37$, $p = .245$, $\eta_p^2 = .02$. The critical analysis is depicted in Figure 2.

To assess the contribution of remember and know judgments on memory performance, additional ANOVAs with the same design were conducted. Significantly more *remember* responses were associated with repeat ($M = 0.53$, $SE = 0.02$) than with switch trials ($M = 0.49$, $SE = 0.02$), $F(1, 77) = 12.75$, $p = .001$, $\eta_p^2 = .14$; *know* responses did not vary with trial type, $F(1, 77) = 1.50$, $p = .225$, $\eta_p^2 = .02$. No other effect was significant, $F < 2.06$, $p > .155$. Thus, the difference in memory performance between switch and repeat trials was due to higher recollection than familiarity.

Follow-up Analysis

In order to explore the relationship between the task switching and memory results and working memory capacity, we analyzed the reading span task. The average reading span was 2.72 ($SD = .95$). This score was not significantly correlated to the scores of hits ($r = -.04$), accuracy ($r = .11$), or reaction times ($r = -.16$). Therefore, working memory capacity did not seem to be related to task or memory performance.

Discussion

The goal of Experiment 1 was to examine whether the conflict produced by task switching affects subsequent memory performance. We used univalent stimuli to test the pure effect of task switching, unconfounded by stimulus bivalency. In the study phase, we found the expected switch costs; thus, the enhanced demands of task switching were associated with an increased encoding time. More importantly, in the test phase, recognition memory was better for repeat than for switch trials, indicating that the conflict triggered by task switching affected subsequent memory performance. Thus, task switching hurts memory encoding for task-relevant information even for univalent stimuli. As expected, this effect was mainly expressed in remember responses.

In Experiment 2, we investigated how the conflict triggered by bivalency further affects memory performance. Toward this goal, we designed a similar experiment as Experiment 1, but we used bivalent material.

Experiment 2

In Experiment 2, we used pictures as stimuli and participants had do classify them as *smaller* or *bigger than a soccer ball* or as *living* or *non-living*. As all the stimuli could be used for both tasks, they were bivalent. Moreover, as we used the same set of response keys for both tasks, a third kind of conflict occurred on some trials, that is, response incompatibility. If a stimulus would require the same key for both tasks, for example, the *a*-key to classify a picture of an elephant as *bigger than a soccer ball* in the size task and as *living* in the animacy task, the response mapping was *compatible*. In contrast, when the stimulus required different response keys for each of the tasks, for example, the *a*-key to classify a house as *bigger than a soccer ball* and the *l*-key to classify it as *non-living*, the response mapping was *incompatible*. For incompatible response mappings, the inappropriate response has to be suppressed and this usually slows down performance (Gade & Koch, 2007; Kornblum, Hasbroucq, & Osman, 1990). We expected lower memory performance for incompatible and switch stimuli due to the presence of conflict. Moreover, we expected a stronger effect for bivalent compared to univalent materials because of the between-task conflict with bivalent materials (Allport et al., 1994; Meier et al., 2009).

Method

Participants and Design

The participants were 40 undergraduate students (4 male and 36 female) from the University of Bern, and all of them were German speaking. The age ranged from 19 to 33 years ($M = 21.79$, $SD = 2.75$), and they participated in the study for course credits. The study was approved by the local ethical committee of the University of Bern, and all participants gave written consent.

Material

A total of 128 colored photographs were used which were collected from a web search (see Footnote 1). They could be classified both as smaller or bigger than a soccer ball and as living or non-living. The stimuli were arranged in separate lists of 64 pictures, counterbalanced across category and trial type, such that each stimulus occurred equally often in the repeat and switch condition and in each task. One of the lists was used in the study phase, and both lists were presented in the test phase. Lists were counterbalanced across participants.

Procedure

The procedure was identical as in Experiment 1 with the following exceptions. Participants were instructed to perform the size task when the stimulus appeared in the upper part of the screen and to perform the animacy task when it appeared in the lower part. The stimuli were presented clockwise, beginning in the upper half on the left, which led to a predictable AABB sequence of the two tasks as depicted in Figure 3. Participants had to press the *a*-key when an object was *bigger than a soccer ball* or *living* and the *l*-key when the object was *smaller than a soccer ball* or *non-living*. After a brief practice phase with 8 trials, participants performed the study phase with 64 trials. After the reading span task which was identical to Experiment 1,

the recognition memory test was administered with 128 stimuli, half of them old and the other half new. The entire experiment lasted about 25 min. All raw data for Experiment 2 are listed in ESM 2.

Analysis

For the study phase, task-switching performance was analyzed using a 2 (Trial Type: switch vs. repeat) × 2 (Response Type: compatible vs. incompatible) ANOVA for both reaction times and accuracy. For the test phase, the proportion of hits and the false alarms were analyzed. As it was not possible to assign the false alarm rates to repeat or switch trials, we used hit rates only as recognition scores (cf. Ortiz-Tudela et al., 2016). Memory performance and the remember/know judgments were analyzed using the same two factors trial type and response type. One participant was excluded because reaction time performance was more than 3 *SD* slower than all other participants. An α level of .05 was used. Effect sizes are expressed as η_p^2 values.

Results

Study Phase

Reaction time analysis revealed that the participants responded significantly faster on repeat (M = 1,098 ms,
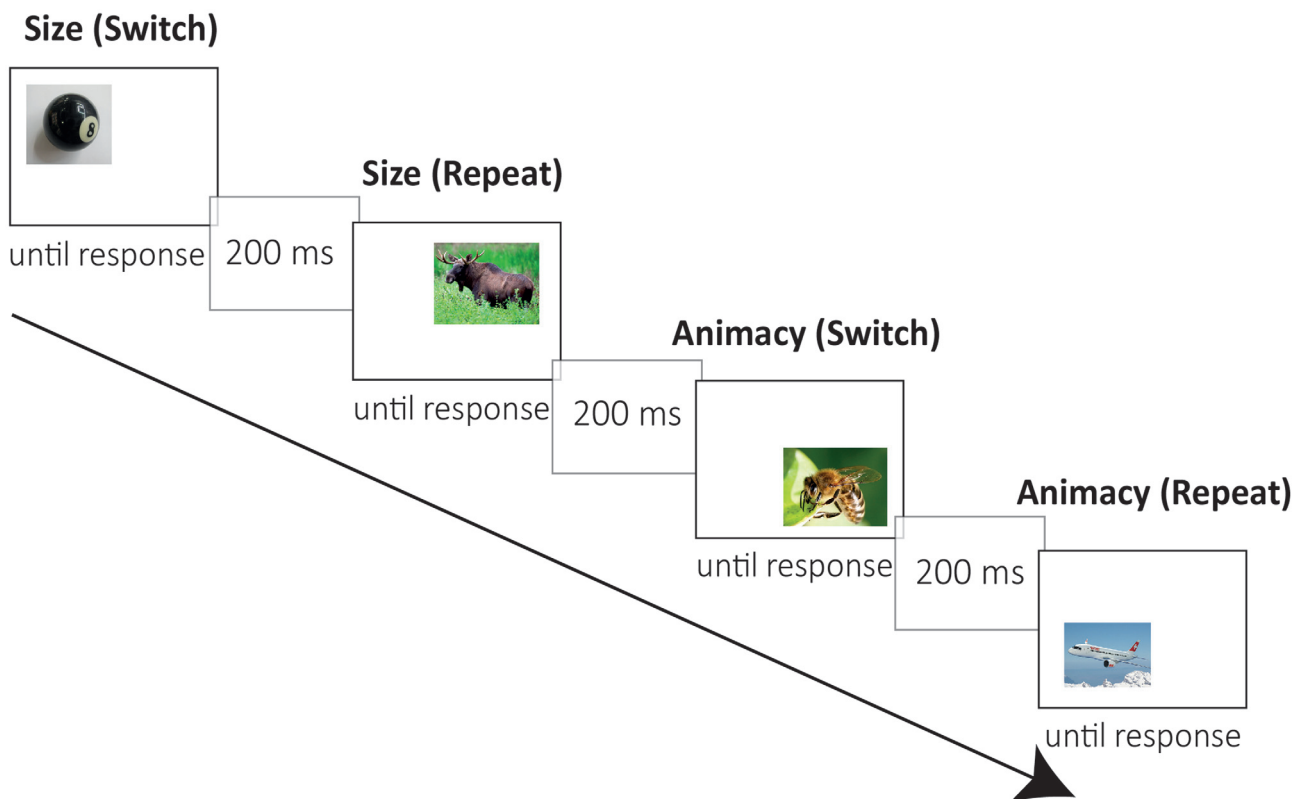
**Figure 3.** Predictable AABB study trial sequence in Experiment 2.

SE = 41) than on switch trials (M = 1,536 ms, SE = 64), $F(1, 38)$ = 118.72, $p < .001$, η_p^2 = .76. Response type, $F(1, 38)$ = .30, p = .59, η_p^2 = .01, and the interaction between trial type and response type were not significant, $F(1, 38) < .01$, p = .99, $\eta_p^2 < .01$.

Accuracy analysis revealed that participants were more accurate on repeat (M = 0.95, SE = 0.01) than on switch trials (M = 0.92, SE = 0.01), $F(1, 38)$ = 10.15, p = .003, η_p^2 = .21. Response type, $F(1, 38)$ = 1.96, p = .170, η_p^2 = .05, and the interaction between response type and trial type were not significant, $F(1, 38) < 1$, p = .922, $\eta_p^2 < .01$.

Test Phase

The proportion of hits was M = 0.76, SE = 0.16 and the proportion of false alarms was M = 0.08, SE = 0.07. Hit rates only for each conflict type were further analyzed, and the results are presented in Figure 4. The ANOVA revealed that repeat stimuli were better recognized (M = 0.80, SE = 0.02) than switch stimuli (M = 0.73, SE = 0.02) as indicated by a main effect of trial type, $F(1, 38)$ = 18.23, $p < .001$, η_p^2 = .32. Neither the main effect of response type, $F(1, 38)$ = .01, p = .92, $\eta_p^2 < .01$, nor the interaction between trial type and response type were significant, $F(1, 38)$ = .56, p = .46, $\eta_p^2 < .01$.

To assess the contribution of recollection and familiarity on memory performance, additional ANOVAs with the same design were conducted. Significantly more *remember* responses were associated with repeat (M = 0.63, SE = 0.03) than with switch trials (M = 0.56, SE = 0.03), $F(1, 38)$ = 11.7, $p < .01$, η_p^2 = .24. In contrast, *know* responses did not vary with trial type, $F(1, 38)$ = 0.11, p = .744, $\eta_p^2 < .01$. No other effect was significant, $F < 2.88$, $p > .098$. Thus, as in Experiment 1, the difference between switch and repeat trials was due to higher recollection than familiarity.
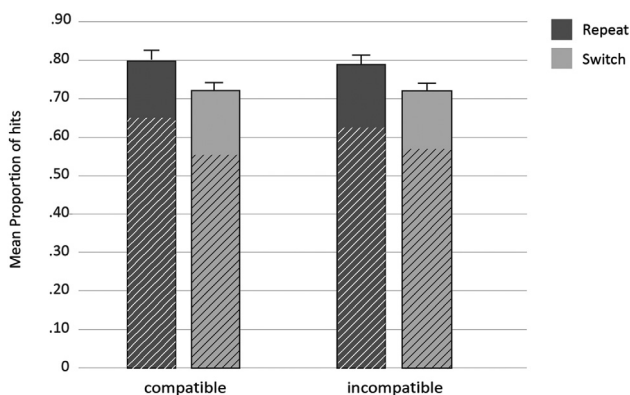
Follow-Up Analysis

The average reading span was 2.59 (SD = 0.68). This score was not significantly correlated to the scores of hits (r = .02), accuracy (r = .17) or reaction times (r = −.12). Again, working memory capacity did not seem to be related to task or memory performance.

Discussion

Experiment 2 replicated and extended the results of Experiment 1. As in Experiment 1, in the study phase, responses were slower and less accurate for switch than for repeat trials. Moreover, the switch costs in Experiment 2 were much larger than in Experiment 1. Crucially, we found again better memory for repeat than for switch trials, as in Experiment 1. In fact, the size of this effect was much stronger with bivalent stimuli (i.e., η_p^2 = .32) than with univalent stimuli (i.e., η_p^2 = .08). As partial eta squared is a reliable measure to compare the effect size of a manipulation across studies (Cohen, 1973; cf. Pedhazur, 1977), this comparison indicates that the memory effect is four times larger with bivalent stimuli than with univalent stimuli. This suggests that with bivalent switch stimuli, encoding of task-relevant information was additionally impaired. In contrast, the conflict produced by response type had neither an effect on task nor on memory performance, suggesting that this conflict was too weak to affect performance.

As in Experiment 1, the difference between repeat and switch stimuli was mainly expressed in remember responses and the contribution was stronger with bivalent stimuli (i.e., η_p^2 = .24) than with univalent stimuli (i.e., η_p^2 = .14). This corroborates that switching task requires attention, and this requirement is enhanced with bivalent stimuli.

General Discussion

The aim of the study was to investigate the impact of task switching on subsequent memory performance. In two experiments, we combined a task-switching procedure with an incidental recognition memory test. The stimuli were either univalent (Experiment 1) or bivalent (Experiment 2); switch and bivalent stimuli were considered as conflict stimuli. Another conflict was induced by incompatible stimulus-response mappings.

The conflict produced by task switching impaired memory performance in both experiments, as memory was lower for switch than for repeat stimuli. As there is no between-task conflict with univalent materials (Mayr & Keele, 2010; Wylie & Allport, 2000), the requirement to reconfigure the task set in switch trials may have produced

Figure 4. Memory performance in Experiment 2. Mean proportion of hits as a function of task switching with bivalent stimuli. The shaded areas reflect *remember*; the solid areas represent *know* responses. Error bars represent standard errors.

this effect in Experiment 1 (Rogers & Monsell, 1995). In Experiment 2, bivalency further impaired memory performance for switch trials, reflected in a larger switch effect than in Experiment 1. The results are in line with the studies by Reynolds et al. (2004) and Richter and Yeung (2012, 2015). They also found lower memory performance with task-relevant switch stimuli. As all the previous studies used bivalent stimuli, our study is the first that provides evidence that even univalent task switching hurts memory encoding for target events.

We suggest that task switching produced interference which resulted in less focused attention toward the target events (Lavie et al., 2004), rather than diminishing a general encoding capacity. In other words, the selectivity of memory encoding was reduced under high cognitive control demands (Richter & Yeung, 2012, 2015). The results of the remember/know procedure revealed that in both experiments, fewer "remember" responses were given for switch than for repeat trials. In contrast, "know" responses did not vary according to the encoding condition. Moreover, the effect of "remember" responses regarding the difference between switch and repeat trials was stronger in Experiment 2 than in Experiment 1. This corresponds with the idea that attention was more focused in repeat than in switch trials, rendering participants more certain about their decisions. Recollection is found to be sensitive to attention manipulations (Yonelinas, 2002). For example, in an experiment by Gardiner and Parkin (1990), participants learned word lists in a full and a divided attention condition. The following word recognition test showed that divided attention reduced the "remember" responses while the "know" responses did not differ. The same pattern was found in our results: Stimuli from repeat trials, in which attention was unimpeded, led to more remember responses than stimuli from switch trials, in which attention had to be shared between target processing and task switching. This effect was more pronounced with bivalent materials, as selecting the appropriate task required more attention due to overlapping stimulus features (Allport et al., 1994; Woodward et al., 2003).

In summary, both task switching and bivalency impair memory. Interestingly, this does not generalize to all kinds of conflict. Studies on the effects of Stroop conflict on subsequent memory performance found *improved* memory performance for Stroop compared to non-conflicting stimuli. For example, in a study by Krebs, Boehler, De Belder, and Egner (2015), faces were presented in a study phase either with congruent information (the word man over a male face) or with incongruent information (the word woman over a male face). The subsequent face recognition test showed that irrelevant incongruent information improved subsequent memory for faces, that is, a conflict-induced memory benefit. Similar results were reported by Rosner, D'Angelo, MacLellan, and Milliken (2015). Their participants had to read one word of a word pair. Half of the items were congruent (the words had the same identity), and the other half were incongruent (the words had different identities). The results of the subsequent recognition test showed better memory for incongruent than for congruent stimuli.

Crucially, in these studies the conflict arose from the co-activation of two incompatible responses (Egner, Delano, & Hirsch, 2007), for example, the picture of a woman with the superimposed word "man" (cf. Krebs et al., 2015). In Stroop conflict, the focus of attention is strategically directed at the target in order to avoid errors (Botvinick et al., 2001; Verguts & Notebaert, 2009). As a consequence, encoding mechanisms are up-regulated, leading to better memory performance for targets. In contrast, in the present study, the conflict arose from selecting the relevant task set in a task-switching environment. When participants have to switch tasks, the focus of attention toward the target is reduced because attention is required for selecting the appropriate task. Therefore, memory performance is reduced in switch trials. In the case of bivalent stimuli, even more attention is required for selecting the relevant task due to the overlapping stimulus features and thus memory performance is further affected.

Conclusion

Finding the most efficient way to execute work procedure is a major issue of mankind. To be efficient, most approaches – as, for example, the TOTE unit (Miller et al., 1960) – favor fast and flexible shifts. While goal-directed performance can be improved by switching tasks, our results suggest that this may be unprofitable for memory: The experiments presented here provide evidence that task switching impairs memory performance for task-relevant materials. Moreover, our study is the first that provides evidence that even task switching with univalent stimuli affects memory encoding.

Electronic Supplementary Materials

The electronic supplementary material is available with the online version of the article at https://doi.org/10.1027/1618-3169/a000431

ESM 1. Data (.sav)
Raw data of Experiment 1.
ESM 2. Data (.sav)
Raw data of Experiment 2.

References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Conscious and nonconscious information processing: Attention and performance XV* (pp. 421–452). Cambridge, MA: MIT Press.

Allport, A., & Wylie, G. (1999). Task switching: Positive and negative priming of task-set. In G. W. Humphreys, J. Duncan, & A. M. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 273–296). Oxford, UK: Oxford University Press.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624–652. https://doi.org/10.1037/0033-295X.108.3.624

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron, 39*, 713–726. https://doi.org/10.1016/S0896-6273(03)00466-5

Chiu, Y. C., & Egner, T. (2016). Distractor-relevance determines whether task-switching enhances or impairs distractor memory. *Journal of Experimental Psychology: Human Perception and Performance, 42*, 1–5. https://doi.org/10.1037/xhp0000181

Cohen, J. (1973). Eta-squared and partial eta-squared in fixed factor ANOVA designs. *Educational and Psychological Measurement, 33*, 107–112.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450–466.

Egner, T., Delano, M., & Hirsch, J. (2007). Separate conflict-specific cognitive control mechanisms in the human brain. *NeuroImage, 35*, 940–948.

Gade, M., & Koch, I. (2007). Cue-task associations in task switching. *The Quarterly Journal of Experimental Psychology, 60*, 762–769. https://doi.org/10.1080/17470210701268005

Gardiner, J. M., & Parkin, A. J. (1990). Attention and recollective experience in recognition memory. *Memory & Cognition, 18*, 579–583.

Jenkins, R., Lavie, N., & Driver, J. (2005). Recognition memory for distractor faces depends on attentional load at exposure. *Psychonomic Bulletin & Review, 12*, 314–320. https://doi.org/10.3758/bf03196378

Jersild, A. T. (1927). Mental set and shift. *Archives of Psychology, 89*, 1–81.

Kanigel, R. (2005). *The one best way: Frederick Winslow Taylor and the enigma of efficiency,* Vol. 1, (1st ed.). Cambridge, MA: The MIT Press.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility – A model and taxonomy. *Psychological Review, 97*, 253–270.

Krebs, R. M., Boehler, C. N., De Belder, M., & Egner, T. (2015). Neural conflict–control mechanisms improve memory for target stimuli. *Cerebral Cortex, 25*(3), 833–843. https://doi.org/10.1093/cercor/bht283

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133*, 339–354. https://doi.org/10.1037/0096-3445.133.3.339

Mayr, U., & Keele, S. W. (2010). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129*, 4–26.

Meier, B., Rey-Mermet, A., Rothen, N., & Graf, P. (2013). Recognition memory across the lifespan: The impact of word frequency and study-test interval on estimates of familiarity

and recollection. *Frontiers in Psychology, 4*, 1–15. https://doi.org/10.3389/fpsyg.2013.00787

Meier, B., Woodward, T. S., Rey-Mermet, A., & Graf, P. (2009). The bivalency effect in task switching: General and enduring. *Canadian Journal of Experimental Psychology – Revue canadienne de psychologie expérimentale, 63*, 201–210.

Miller, G. A., Galanter, E., & Pribam, K. (1960). *Plans and the structure of behavior*. New York, NY: Holt, Rinehart & Winston.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In R. J. Davidson, R. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (Vol. 4, pp. 1–18). New York, NY: Plenum Press.

Ortiz-Tudela, J., Milliken, B., Botta, F., LaPointe, M., & Lupiañez, J. (2016). A cow on the prairie vs. a cow on the street: Long-term consequences of semantic conflict on episodic encoding. *Psychological Research, 81*, 1264–1275. https://doi.org/10.1007/s00426-016-0805-y

Pedhazhur, E. J. (1977). *Multiple regression in behavioral research*. Fort Worth, TX: Harcourt Brace.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Rey-Mermet, A., & Meier, B. (2012). The bivalency effect: Evidence for flexible adjustment of cognitive control. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 213–221. https://doi.org/10.1037/a0026024

Reynolds, J. R., Donaldson, D. I., Wagner, A. D., & Braver, T. S. (2004). Item- and task-level processes in the left inferior prefrontal cortex: Positive and negative correlates of encoding. *NeuroImage, 21*, 1472–1483. https://doi.org/10.1016/j.neuroimage.2003.10.033

Richter, F. R., & Yeung, N. (2012). Memory and cognitive control in task switching. *Psychological Science, 23*, 1256–1263. https://doi.org/10.1177/0956797612444613

Richter, F. R., & Yeung, N. (2015). Corresponding influences of top-down control on task switching and long-term memory. *The Quarterly Journal of Experimental Psychology, 68*, 1124–1147. https://doi.org/10.1080/17470218.2014.976579

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.

Rosner, T. M., D'Angelo, M. C., MacLellan, E., & Milliken, B. (2015). Selective attention and recognition: Effects of congruency on episodic learning. *Psychological Research, 79*, 411–424. https://doi.org/10.1007/s00426-014-0572-6

Shaffer, L. H. (1965). Choice reaction with variable S–R mapping. *Journal of Experimental Psychology, 70*, 284–288.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology, 26*, 1–12.

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136*, 601–626. https://doi.org/10.1037/a0019791

Verguts, T., & Notebaert, W. (2009). Adaptation by binding: A learning account of cognitive control. *Trends in Cognitive Sciences, 13*, 252–257. https://doi.org/10.1016/j.tics.2009.02.007

Woodward, T. S., Meier, B., Tipper, C., & Graf, P. (2003). Bivalency is costly: Bivalent stimuli elicit cautious responding. *Experimental Psychology, 50*, 233–238.

Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs". *Psychological Research, 63*, 212–233.

Yeung, N., Nystrom, L. E., Aronson, J. A., & Cohen, J. D. (2006). Between-task competition and cognitive control in task switching. *Journal of Neuroscience, 26*, 1429–1438. https://doi.org/10.1523/JNEUROSCI.3109-05.2006

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46*(3), 441–517. https://doi.org/10.1006/jmla.2002. 2864

ORCID
Beat Meier
https://orcid.org/0000-0003-3303-6854

Beat Meier
Institute of Psychology
University of Bern
Fabrikstr. 8
3012 Bern
Switzerland
beat.meier@psy.unibe.ch

ORIGINAL ARTICLE

Different impact of task switching and response-category conflict on subsequent memory

Michèle C. Muhmenthaler[1] · Beat Meier[1]

Abstract

The impact of cognitive control demands on long-term memory is mixed, with some conflicts leading to better, others leading to worse subsequent memory. The current study was designed to investigate how different types of cognitive control demands modulate the effects on memory. At study, participants had to switch between two classification tasks and later, free recall performance was assessed. The stimuli consisted of two interleaved words, one word had to be categorized and the other word had to be ignored. In four experiments, the congruency between target and ignored words was manipulated by changing the distractor category. This allowed us to investigate the impact of different types of conflict (i.e., task switching, perceptual load, response-category conflict, stimulus-category conflict). The results revealed that task switching impaired memory in all experiments. In Experiment 1, higher perceptual load also impaired memory. Experiments 2–4 showed that the co-activation of two words which required different responses (i.e., response-category conflict) enhanced memory performance but only when the conflict stimuli were presented in pure blocks. Overall, memory performance seems to depend on attentional policies. Withdrawing attention from target encoding results in lower memory performance. In contrast, focusing attention on the target results in enhanced memory performance.

Introduction

Cognitive control enables us to regulate and coordinate thoughts and actions according to our internal goals (Braver, 2012; Posner & Snyder, 1975). Core elements of cognitive control are to protect goal-relevant behavior against distraction, to detect and resolve conflict and to update behavior in response to changing goals and circumstances (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Monsell, 2003). Substantial theoretical and experimental progress has been made regarding the impact of cognitive control on immediate task performance. Larger cognitive control demands at encoding constantly slow down performance and increase the error

rates (Allport, Styles, & Hsieh, 1994; Cohen, Dunbar, & McClelland, 1990; Egner, Delano, & Hirsch, 2007; Gratton, Coles, & Donchin, 1992; Mayr & Keele, 2000; Meier & Rey-Mermet, 2012; Meier, Woodward, Rey-Mermet, & Graf, 2009; Rogers & Monsell, 1995). Recently, the long-term consequences of cognitive control has been addressed, that is, the consequences on memory (Davis, Rosner, D'Angelo, MacLellan, & Milliken, 2019; Krebs, Boehler, De Belder, & Egner, 2015; Ortiz-Tudela, Milliken, Botta, LaPointe, & Lupiañez, 2017; Richter & Yeung, 2012, 2015; Rosner, D'Angelo, MacLellan, & Milliken, 2015; Rosner, Davis, & Milliken, 2015; Yue, Castel, & Bjork, 2013). Interestingly, some studies showed that larger control demands at encoding increased later memory performance while other studies showed that larger control demands at encoding decreased subsequent memory performance. In the present study, we combined different types of control demands and assessed their consequences on memory. The aim was to investigate systematically how different types of cognitive control demands affect subsequent memory performance and to explore the underlying mechanisms.

The consequences of cognitive control are usually assessed through testing subsequent memory for the stimuli that produce conflict at encoding. In a study phase, the

✉ Michèle C. Muhmenthaler
   michele.muhmenthaler@psy.unibe.ch

   Beat Meier
   beat.meier@psy.unibe.ch

1   Institute of Psychology, University of Bern, Fabrikstrasse 8, 3012 Bern, Switzerland

control demands vary and in a later test phase, memory is assessed. For example, in a study by Krebs et al. (2015), participants performed a Stroop-like task. Male or female faces were overlaid with the words man, house or woman, thus congruent, neutral and incongruent face-word stimuli were created. The participants had to judge the gender of the face, while ignoring the superimposed word. The *incongruent* condition triggered a response-category conflict as the face and the distractor word required different responses. On incongruent trials, performance was slowest, but on the subsequent recognition memory test, these faces showed better memory performance, that is, a conflict-induced benefit. The authors argued that the emerging conflict in the incongruent condition served as an internal signal for reinforcing top-down attention to task-relevant information and that encoding mechanisms for incongruent targets were up-regulated which led to better memory (Botvinick et al., 2001; Egner & Hirsch, 2005).

In a related study, participants had to read one word of a pair of spatially interleaved words (Rosner, D'Angelo et al., 2015). Half of the stimuli were congruent (the words had the same identity) and the other half were incongruent (the words had different identities). Performance was slower in the incongruent condition and the results of the subsequent recognition test showed better memory performance for incongruent trials. The authors suggested that selective attention demands for incongruent stimuli cued learning processes which led to enhanced recognition memory.

Other researchers used a task-switching paradigm to investigate the impact of different control demands on memory (Chiu & Egner, 2016; Muhmenthaler & Meier, 2019; Reynolds, Donaldson, Wagner, & Braver, 2004; Richter & Yeung, 2012, 2015). In task-switching experiments, participants perform a series of simple tasks. On some trials, the task changes (switch trials), and on other trials, the task is repeated (repeat trials). For switch trials, an increase in cognitive control is necessary to reconfigure the task set (Rogers & Monsell, 1995). Moreover, as usually bivalent stimuli are used (i.e., stimuli that can be used to perform two tasks), an interference produced by overlapping stimulus features also occurs (Allport et al., 1994; Allport & Wylie, 1999; Woodward, Meier, Tipper, & Graf, 2003). Task switching is associated with performance costs (referred to as switch costs), in terms of slower task performance and increased error rates (Jersild, 1927; Meiran, 2000; Rogers & Monsell, 1995). In a study by Reynolds et al. (2004), participants had to categorize words according to two dimensions. In one condition, they had to perform one task alone (single-task block) and in another condition, they had to perform two tasks in alternating runs (task-switching block). In the task-switching block, performance was slower and less accurate and recognition memory was worse compared to the single-task block. This suggests that the requirement to switch task

impaired later memory performance, that is, a memory cost induced by larger control demands.

In a more recent study, we extended this line of research in two experiments (Muhmenthaler & Meier, 2019). In Experiment 1, we used univalent materials, that is, stimuli that can only be used to perform one task. The results revealed that task switching impaired memory performance. In a second experiment with bivalent materials, this effect was even stronger, suggesting that the larger cognitive demands of bivalent compared to univalent switch trials further hurt memory encoding for task-relevant information.

Richter and Yeung (2012) investigated the impact of task switching on recognition memory for attended and unattended stimuli. They used compound stimuli which consisted of picture–word pairs and participants had to switch between classifying pictures versus words. The results showed that task switching compared to task repetition resulted in less confident recognition of the attended targets but to more confident recognition of unattended stimuli. The authors suggested that task switching impaired encoding of task-relevant information but facilitated encoding of task-irrelevant information by affecting the selectivity of memory encoding.

Together, memory performance for targets was impaired in all studies when participants had to switch task. This is in line with the assumption that the increased control demands in switch trials reduce top-down attention toward the targets (Richter & Yeung, 2015). In other words, attention is devoted to task operations which result in less-efficient target encoding and in more distractor intrusions (Lavie, Hirst, De Fockert, & Viding, 2004; Richter & Yeung, 2012).

In summary, the literature on the interplay of cognitive control at encoding and subsequent memory showed a memory benefit for incongruent compared to congruent stimuli. In contrast, there is a memory cost when participants had to switch task. In the present study, we aimed to combine these two effects to produce opposing effects on memory. Toward this goal, we used congruent and incongruent stimuli and embedded them in a task-switching procedure in the study phase. Then, we tested memory performance. Instead of a recognition test, we applied a free recall test in all experiments. Our rationale was that for free recall, more self-initiated processing is required, thus stronger effects should materialize (cf. Craik, 1986).

To anticipate the results, task switching consistently impaired memory in all experiments. However, enhancing memory with incongruent stimuli turned out to be more difficult. In Experiment 1, we used the experimental setup by Rosner, D'Angelo et al. (2015) but found opposing effects (lower memory for incongruent stimuli). Therefore, in Experiment 2, we changed the incongruent condition from a perceptual level to the level of the response category. Nevertheless, we still found no beneficial effect for congruency in Experiment 2. In Experiment 3 (https://aspredicte

d.org/re78g.pdf), we blocked the incongruent and congruent stimuli to foster appropriate attentional strategies and we finally found enhanced memory for incongruent targets. In Experiment 4 (https://aspredicted.org/53si7.pdf), we tested a potential confound and excluded the possibility that the effect of Experiment 3 emerged simply due to different stimulus categories.

Experiment 1

In Experiment 1, we combined the experimental design involving incongruency used by Rosner, D'Angelo et al. (2015) and the design used in our previous study which involved task switching (cf. Experiment 1; Muhmenthaler & Meier, 2019). In the study phase, participants had to switch between two semantic classification tasks in a predictable AABB order (cf. Rogers & Monsell, 1995). The stimuli consisted of two spatially interleaved trial-unique words (cf. Rosner, D'Angelo et al., 2015). In both tasks, participants had to categorize one of these words. Half of the stimuli were congruent (the two interleaved words were the same) and the other half were incongruent (the two interleaved words had different identities). We hypothesized that memory would be higher for incongruent stimuli compared to congruent ones, based on previous results and on the general idea that selective attention demands enhanced memory (Krebs et al., 2015; Rosner, D'Angelo et al., 2015). Moreover, we hypothesized that memory for targets shown in switch trials would be lower than memory for targets shown in repeat trials as larger control demands reduce encoding of task-relevant information (Dreisbach & Wenke, 2011; Lavie et al., 2004; Richter & Yeung, 2012).

Method

Participants

The participants were 84 German-speaking volunteers from the general population (36 male and 48 female). The age ranged from 18 to 29 years ($M = 22.23$, SD 2.67). They were recruited by word of mouth and did not get any financial compensation. In an a priori power analyses (Cohen, 1988), we computed the sample size as a function of the required power level, the significance level and the population effect size which we expected (Faul, Erdfelder, Lang, & Buchner, 2007). We used the effect size for congruency ($d = 0.65$) from the study of Rosner, D'Angelo, et al. (2015) and a significance level of 0.05 and 0.90 as power level. The analysis computed a minimum of 74 participants as sample size. The study was approved by the ethical committee of the University of Bern and all participants gave written consent.

Fig. 1 Experiment 1. Depiction of a congruent stimulus (left) involving two identical words and an incongruent stimulus (right), involving two different words from the same category

Materials

The experiment contained 36 compound word stimuli, 4 for practice and 32 for the experimental block.[1] The compound stimuli consisted of two interleaved words which were presented in the middle of the screen as shown in Fig. 1 (cf. Milliken & Joordens, 1996; Rosner, D'Angelo, et al., 2015). One of the two words was displayed in red and the other in green against a white background in *Lucida Console* font. An experimental trial consisted either of two identical words (congruent), or two different words from the same category (incongruent). The words were exemplars of the four categories birds, mammals, music instruments and kitchen utensils and consisted of three to eight letters (cf. Muhmenthaler & Meier, 2019). For incongruent trials, the length of the words differed by a maximum of one character, the target word was always as long or longer than the distractor word. Birds and mammals were used for an animal decision task and kitchen utensils and music instruments were used for an object decision task. Word color and position were counterbalanced within each condition, so that a red target word was at the top for one half of both, congruent and incongruent trials, and at the bottom for the other half. Half of the stimuli were congruent, the other half incongruent. A total of 54 words were used (18 targets in the congruent condition, 18 targets and 18 distractors in the incongruent condition).

Procedure

Participants were tested in groups in a computer laboratory.

Study phase

In the study phase, participants were informed that they will see two words on the computer screen (one red, one green) and that they will have to categorize the red word and to ignore the green word. They were instructed to switch between two classification tasks and to perform each task twice in succession. A schematic trial sequence is depicted in Fig. 2. (The words were presented in German).

---

[1] Materials used to conduct the research (including analysis code) will be made available to other researchers for purposes of replicating the procedure or reproducing the results by email to the corresponding author.

Fig. 2 Experiment 1. Trial sequence of the study phase. Task order was a predictable AABB sequence
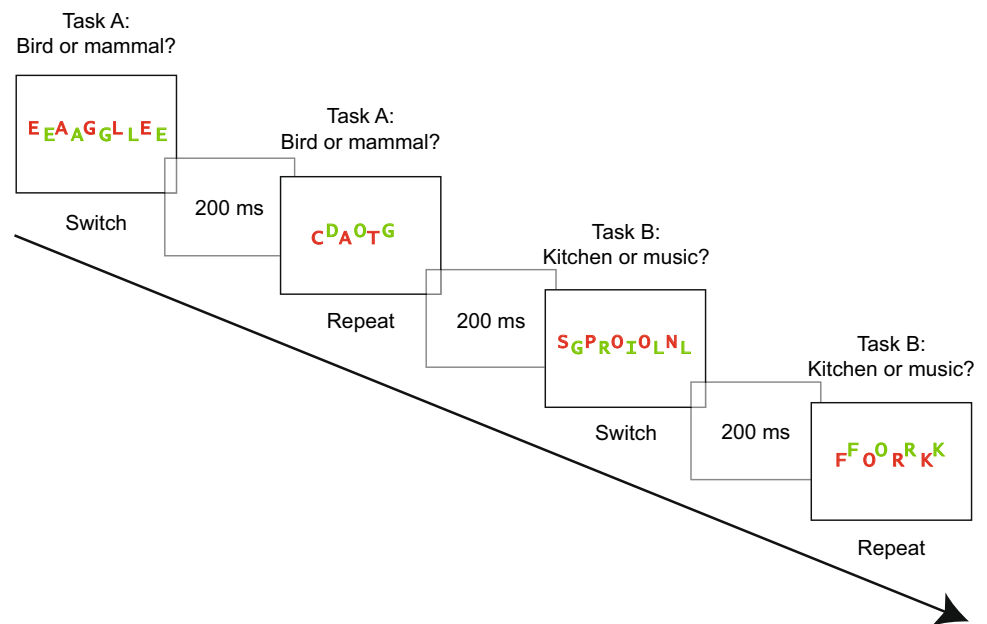
In the first task, participants had to decide whether the target word was a mammal or a bird and in the second task, they had to determine if the target word was a music instrument or a kitchen utensil. They had to press the a-key for a mammal in the animal task and a music instrument in the object task and they had to respond the l-key for a bird in the animal task and a kitchen utensil in the object task. Participants were instructed to respond as quickly and correctly as possible, but they were not informed that they would be asked to recall the stimuli later. The stimuli were presented in the middle of the screen until response, in random order, with a response-stimulus interval of 200 ms. After a brief practice phase with 4 trials, participants performed the study phase with 32 trials. The stimuli were counterbalanced across participants, so that each word occurred equally often in each condition and position, and each word was presented only once to each participant. Sixteen congruent and 16 incongruent compound stimuli were presented in randomized order, counterbalanced across trial type (repeat vs. switch). Thus, each condition involved eight experimental trials.

Test phase

The test phase consisted of a surprise free recall test. Participants received paper and pencil, and they were instructed to write down all the words they remembered from the study phase. They had 3 min to complete this task. The entire experiment lasted about 15 min.

Statistical analyses

We computed the median of the reaction times (RTs) for each participant and each condition, error trials were excluded from RT analyses. Task switching performance at study was analyzed using a 2 (trial type: repeat vs. switch) × 2 (congruent vs. incongruent) analysis of variance (ANOVA) with repeated measures on correct RTs and response accuracy. Memory performance at test was analyzed with the same ANOVA. For each participant, the proportion of recalled words was computed for each condition. An alpha level of 0.05 was used for all statistical tests. Effect sizes are expressed as partial η^2 values.

Results

Study phase

RTs were faster for repeat ($M = 1760$ ms, SE 64 ms) than for switch trials ($M = 2065$ ms, SE 70 ms), $F(1, 83) = 65.66$, $p < 0.001$, $\eta_p^2 = 0.44$, indicating that the expected switch costs occurred. Responses were slower for incongruent ($M = 2092$ ms, SE 72 ms) than for congruent stimuli ($M = 1733$ ms, SE 63 ms), $F(1, 83) = 75.49$, $p < 0.001$, $\eta_p^2 = 0.48$. The main effect was qualified by an interaction, $F(1, 83) = 11.05$, $p = 0.001$, $\eta_p^2 = 0.12$. RTs for incongruent trials ($M = 1859$ ms, SE 73 ms for repeat, respectively, $M = 2326$ ms, SE 83 ms for switch stimuli) were stronger affected by trial type ($t(83) = 7.17$, $p < 0.001$, $d = 0.78$) than
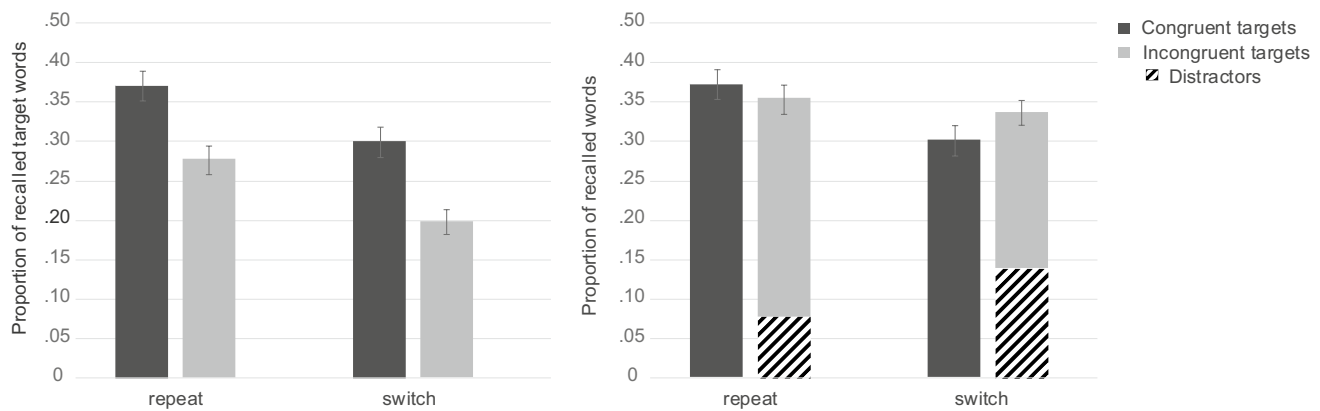
Fig. 3 Experiment 1. Free recall performance for target words as a function of congruency modulated by trial type (left). The shaded areas reflect the distractors and the solid bars the targets (right). Error bars represent standard errors

RTs for congruent trials ($M = 1661$ ms, SE 70 ms for repeat, respectively, $M = 1804$ ms, SE 64 ms for switch stimuli), $t(83) = 2.46$, $p = 0.016$, $d = 0.27$.

The same ANOVA on accuracy revealed that performance was generally high ($M = 0.94$, SE 0.01). Accuracy was significantly lower for switch ($M = 0.91$, SE 0.01) than for repeat trials ($M = 0.97$, SE 0.01), $F(1, 83) = 44.60$, $p < 0.001$, $\eta_p^2 = 0.35$. Moreover, accuracy was significantly lower for incongruent ($M = 0.92$, SE 0.01) than for congruent stimuli ($M = 0.96$, SE 0.01), $F(1, 83) = 20.72$, $p < 0.001$, $\eta_p^2 = 0.20$. The main effects were qualified by a significant interaction, $F(1, 83) = 14.45$, $p < 0.001$, $\eta_p^2 = 0.15$. In the switch condition, accuracy was substantially lower for incongruent ($M = 0.87$, SE 0.01) than for congruent trials ($M = 0.94$, SE 0.01), $t(83) = 4.96$, $p < 0.001$, $d = 0.54$, whereas in the repeat condition, accuracy was almost equal for congruent ($M = 0.97$, SE 0.01) and for incongruent trials ($M = 0.96$, SE 0.01), $t(83) < 1$, $p = 0.333$, $d = 0.11$.

Test phase

For the test phase, overall free recall performance was $M = 0.29$ (SE 0.01), thus on average, participants correctly recalled 9.3 out of 32 target words. The average proportion of intrusions was 0.77 words (SE 0.14), however, as they cannot be assigned to any condition, we do not discuss them further. We first analyzed target memory performance with an ANOVA with the same two within-subject variables trial type (repeat, switch) and congruency (congruent, incongruent), see Fig. 3. As hypothesized, participants recalled more target words from repeat ($M = 0.32$, SE 0.01) than from switch trials ($M = 0.25$, SE 0.01) and this difference was significant, $F(1, 83) = 32.24$, $p < 0.001$, $\eta_p^2 = 0.28$. Against expectations, free recall performance for incongruent targets was significantly lower ($M = 0.24$, SE 0.01) than for

congruent targets ($M = 0.34$, SE 0.01), $F(1, 83) = 33.62$, $p < 0.001$, $\eta_p^2 = 0.29$. The interaction between trial type and congruency was not significant, $F(1, 83) < 1$, $p = 0.811$, $\eta_p^2 < 0.01$.

In a second step, we also analyzed memory performance for distractors (see Fig. 3). A two-tailed paired sample t test revealed that significantly more distractors were recalled from the switch ($M = 0.14$, SE 0.01) than from the repeat condition ($M = 0.08$, SE 0.01), $t(83) = 3.51$, $p = 0.001$, $d = 0.38$.

Discussion

Experiment 1 investigated whether the different control demands associated with task switching and incongruency at encoding affect subsequent free recall performance. In the study phase, participants had to switch between two semantic classification tasks, half of the stimuli were congruent (two identical words) and the other half incongruent (two different words). In the test phase, switch and incongruent stimuli impaired subsequent free recall performance. This was expected for switch stimuli as it replicated previous results (Muhmenthaler & Meier, 2019; Reynolds et al., 2004; Richter & Yeung, 2012, 2015). The enhanced control demands in switch trials withdrew attention from target processing which led to a less successful encoding for the target words. As we used univalent stimuli, the results were not influenced by stimulus bivalency as in other studies (Chiu & Egner, 2016; Richter & Yeung, 2012). Our results rather suggest that the task switching requirements affected stimulus-processing priorities (Lavie et al., 2004). This resulted in lower memory for targets but also in increased distractor encoding in switch trials, see Fig. 3 on the right side. The latter pattern replicates previous studies (Richter & Yeung, 2012, 2015).

In contrast, the finding that incongruent stimuli impaired memory was unexpected. Our experimental design was based on the study by Rosner, D'Angelo, et al. (2015). Their results showed higher memory for incongruent stimuli, but our results showed the opposite, lower memory performance for incongruent stimuli. However, a critical difference between our study and the study by Rosner et al. is that incongruency was somewhat different. In Rosner et al.'s study, participants had to read one word of a word pair in the incongruent condition, thus the target and the distractor words led to different responses, namely reading one or the other word out aloud. Therefore, a response-category conflict emerged, resulting from the co-activation of two incompatible responses (Egner et al., 2007). In contrast, in our study, participants had to categorize one of two words. As the target and the distractor in incongruent trials stemmed from the same category (e.g., two mammals in the animal task) they always required the same response. Thus, the incongruent stimuli were incongruent on a perceptual or semantic level but not response-incongruent. We reasoned that the presence of a response-category conflict may have been crucial for the memory effect in Rosner, D'Angelo et al. (2015). Accordingly, the conflict triggered by incompatible responses (reading one or the other word) led to a strategical allocation of attention toward the target word to avoid errors. In other words, participants counteracted the response-category conflict by focusing attention selectively to the target and this resulted in higher subsequent memory performance.

The same explanation can be applied to the results of Krebs et al. (2015). In their study, participants had to judge the gender of a face while ignoring the distractor word man, woman or house. An incongruent trial consisted for example of a picture of a female face and the superimposed word man, thus the target and distractor pointed to different responses. The face recognition test revealed that memory was better for incongruent stimuli compared to neutral and congruent stimuli, indicating that incongruent stimuli signaled a requirement to focus attention to the target which resulted in enhanced memory. The fact that congruent and neutral stimuli led to similar memory performance implies that incongruency in terms of a semantic mismatch in the neutral condition did not affect memory. Similarly, in the incongruent condition of our current experiment, the two words required the same response as they stemmed from the same category; therefore, focusing attention solely to the target may have been unnecessary. According to this logic, we would expect a null effect for congruency but our results revealed that even more congruent target words were recalled than incongruent ones.

A possible explanation for this result is the higher perceptual load in the incongruent condition due to the presentation of two different words instead of two identical words (Lavie, Lin, Zokaei, & Thoma, 2009). A combined analysis of all words showed that an equal amount of words from the incongruent and the congruent condition were recalled when the distractors were taken into account, as depicted in the right part of Fig. 3. This indicates that the higher perceptual load in incongruent trials rather affected the allocation of attention and not encoding per se. The presentation of two different words from the same category could have led to a spread of attention toward the distractor as this could optimize performance (Ahissar & Hochstein, 2000). This effect was more pronounced in switch trials, indicating that task switching further reduced the ability to focus on task-relevant information (Lavie et al., 2004; Richter & Yeung, 2012, 2015).

A limitation of this experiment was the different set sizes in the congruent and in the incongruent condition. By design, participants saw the same word twice on each congruent trial (as in Rosner et al.'s study). Thus, even when they attended to the green distractor word, they still encoded the correct word which could have contributed to the better memory performance for congruent targets in our study.

As our initial goal was to produce conflict-enhanced and switch-impaired memory, we kept the perceptual load constant in a next experiment and introduced a response-category conflict. Toward this goal, we used two words from different categories of the same task in the incongruent condition (e.g., animal task). Thus, the words required a different response (e.g., a bird requiring the *l*-key and a mammal requiring the *a*-key). In the congruent condition, we also used two different words, but from the same category, thus both words required the same response (see Fig. 4). As a consequence, the congruent condition of Experiment 2 was identical to the incongruent condition of Experiment 1.
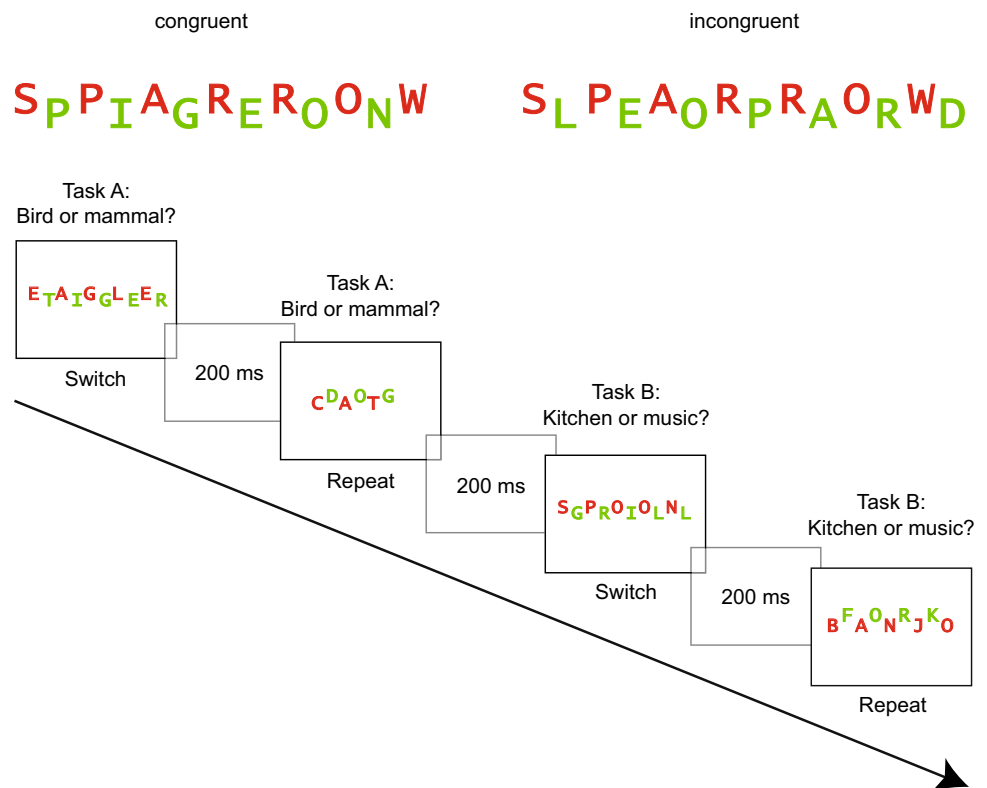
Experiment 2

In Experiment 2, we combined task switching with a response-category conflict. We hypothesized that memory for incongruent targets would be higher due to the possibility to counteract the response-category conflict by focusing attention to the target (Botvinick et al., 2001; Krebs et al., 2015). We further hypothesized that memory for targets in switch trials would be lower than memory for targets in repeat trials due to higher control demands in switch trials.

Method

Participants

The participants were 42 undergraduate German-speaking students from the University of Bern and they participated for course credits ($M = 22.28$ years, SD 3.35, 5 male and 37 female). In an a priori power analysis (Cohen, 1988), we

Fig. 4 Experiment 2. Top: example of a congruent and an incongruent stimulus. Bottom: trial sequence of the study phase. Task order was a predictable AABB sequence. Congruent and incongruent stimuli were presented in randomized order

computed the sample size as a function of a power level of 0.90, a significance level of 0.05, and the expected joint effect size for task switching and response-category conflict of approximately $f = 0.25$ based on the observations in Experiment 1. The resulting analysis computed a number of 36 participants as an optimal sample size. As the effect for congruency was difficult to estimate, sample size considerations were also based on related studies (Krebs et al., 2015; Rosner, D'Angelo, et al., 2015). In these studies, not more than 24 participants were tested. The study was approved by the local ethical committee and all participants gave written consent.

Materials

The word materials were the same as in Experiment 1 but we added 18 new words. A total of 72 words were used, 18 from each category, they were used for 36 congruent and 36 incongruent stimuli. Four stimuli were used for practice and 32 for the experimental trials. In the congruent condition the two words derived from the same category within one task, thus they required the same response (e.g., two mammals). In the incongruent condition, the words derived from different categories within one task, thus they required different responses (e.g., a mammal and a bird). An example of a congruent and an incongruent stimulus is depicted in Fig. 4.

Procedure

The procedure was similar as in Experiment 1, with the exception that the participants were tested individually in a computer laboratory. A schematic trial sequence is depicted in Fig. 4. (Actually, the words were presented in German).

Statistical analyses

Data preparation was as in Experiment 1. We used a 2 (trial type: switch vs. repeat) × 2 (congruent, incongruent) ANOVA with repeated measures. For the study phase, we analyzed RTs for correctly classified stimuli and response accuracy. We excluded three participants due to accuracy below 0.70. For the test phase, the proportion of recalled words was computed for each participant and each condition. An alpha level of 0.05 was used for all statistical tests. Effect sizes are expresses as partial η^2 values.

Results

Study phase

RTs were faster for repeat ($M = 1536$ ms, SE 73 ms) than for switch trials ($M = 1868$ ms, SE 64 ms), $F(1, 38) = 39.04$, $p < 0.001$, $\eta_p^2 = 0.51$, indicating that the expected switch costs
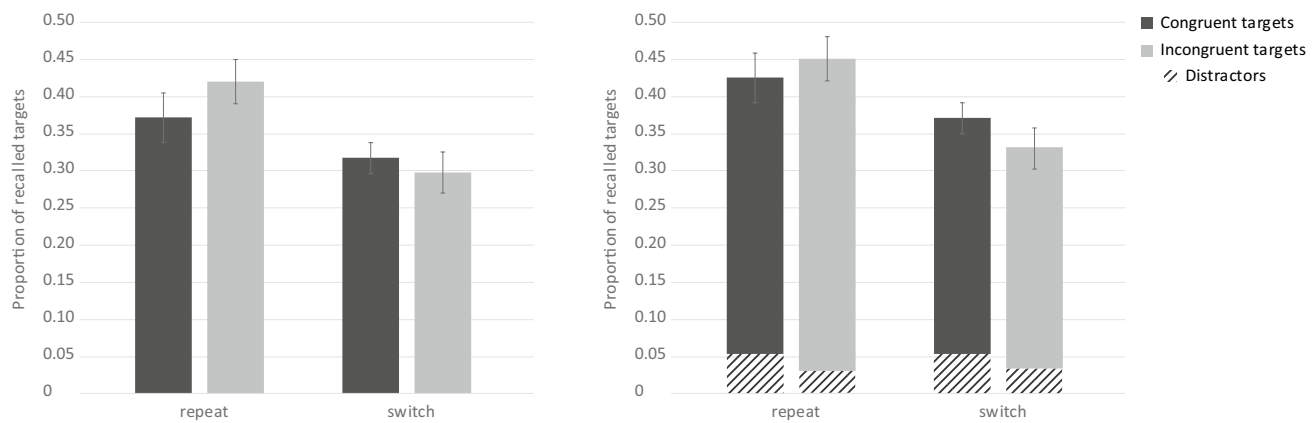
Fig. 5 Experiment 2. Free recall performance for target words as a function of congruency modulated by trial type (left). The shaded areas reflect the distractors and the solid bars the targets (right). Error bars represent standard errors

occurred. The RTs for incongruent ($M = 1688$ ms, SE 63 ms) and congruent trials did not differ ($M = 1716$ ms, SE 70 ms), $F(1, 38) < 1$, $p = 0.469$, $\eta_{p}^2 = 0.01$. The interaction between trial type and congruency was not significant $F(1, 38) < 1$, $p = 0.865$, $\eta_{p}^2 < 0.01$.

The same ANOVA on accuracy revealed that performance was generally high ($M = 0.92$, SE 0.01). Responses were more accurate for repeat ($M = 0.93$, SE 0.01) than for switch trials ($M = 0.90$, SE 0.01), and this difference was significant, $F(1, 38) = 5.57$, $p = 0.023$, $\eta_{p}^2 = 0.13$. Responses were significantly more accurate for congruent ($M = 0.94$, SE 0.01) than for incongruent trials ($M = 0.89$, SE 0.02), $F(1, 36) = 4.89$, $p = 0.033$, $\eta_{p}^2 = 0.12$. The interaction between trial type and congruency was not significant, $F(1, 38) < 1$, $p = 0.821$, $\eta_{p}^2 < 0.01$.

Test phase

Overall free recall performance for the targets was $M = 0.35$ (SE 0.02), thus on average, participants correctly recalled 11.2 out of 32 target words. The average proportion of intrusions was 0.68 words (SE 0.15). The detailed results are depicted in Fig. 5. An ANOVA conducted with the two same within-subject factors trial type and congruency revealed better memory for target words from repeat ($M = 0.40$, SE 0.03) than from switch trials ($M = 0.31$, SE 0.02) and this difference was significant, $F(1, 38) = 13.07$, $p = 0.001$, $\eta_{p}^2 = 0.26$. Free recall performance for incongruent targets was slightly better ($M = 0.36$, SE 0.02) than for congruent targets ($M = 0.35$, SE 0.03), but this difference did not reach significance, $F(1, 38) < 1$, $p = 0.583$, $\eta_{p}^2 = 0.01$. The interaction between trial type and congruency was not significant, $F(1, 38) = 1.54$, $p = 0.223$, $\eta_{p}^2 = 0.04$.

In a next step, we analyzed distractors. The ANOVA with the within-subject factors trial type and congruency revealed

that a same amount of distractors were recalled from repeat ($M = 0.04$, SE 0.01) and from switch trials ($M = 0.04$, SE 0.01), $F(1, 38) < 1$, $p = 0.881$, $\eta_{p}^2 < 0.01$. Distractors from congruent trials ($M = 0.05$, SE 0.01) were more often recalled than distractors from incongruent trials ($M = 0.03$, SE 0.01), $F(1, 38) = 5.89$, $p = 0.020$, $\eta_{p}^2 = 0.13$. The interaction between trial type and congruency was not significant, $F(1, 38) < 1$, $p = 0.910$, $\eta_{p}^2 < 0.01$. However, due to a potential floor effect, these results must be interpreted with caution.

Discussion

Experiment 2 investigated whether different control demands associated with task switching and response-category conflict would affect subsequent free recall performance. As in Experiment 1, participants had to switch between two tasks in a study phase in an AABB order, half of the stimuli were congruent (the two words required the same response) and the other half was incongruent (the two words required different responses). The perceptual load was kept constant, two different words were presented in both conditions. Task switching impaired performance in terms of slower reaction times and lower accuracy. The results also revealed that the subsequent free recall performance was lower when participants had to switch task: less targets from switch trials were recalled than from repeat trials, suggesting that attention was less focused on target processing under high control demands (Lavie et al., 2004; Muhmenthaler & Meier, 2019; Richter & Yeung, 2012).

Reaction times for congruent and incongruent stimuli did not differ, but an effect of accuracy emerged. Accuracy was lower for incongruent stimuli, indicating that these stimuli were perceived as more conflicting. Typically, in studies on the congruency effect, performance is also slowed on

incongruent trials. However, in these studies, the number of stimuli is small and repeated (e.g., numbers), and thus automatic stimulus–response associations are established and stimulus-related variance is reduced (e.g., Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008). In the present study, the number of stimuli was much larger and each stimulus was only presented once. Thus, it is not possible to establish stimulus–response associations and this may explain the lack of a congruency effect at study. It is nevertheless the case that processing incongruent compared to congruent stimuli involves cognitive conflict as the target and distractor require different responses (Egner et al., 2007).

Notably, free recall performance was only numerically enhanced for incongruent compared to congruent targets. However, congruent and incongruent stimuli were presented in randomized order, that is, in a mixed block. This methodological feature may have reduced the effect of incongruency on subsequent memory. In mixed blocks, performance is usually slower compared to pure blocks, even when these blocks are incongruent (Duncan, 1977) and trial-to-trial adaptions would be necessary on about half of the trials (Los, 1994). Thus, there is no clear optimal strategy and participants may abstain from any level-specific preparation (Los, 1999). They may adopt a "worst-case scenario" which involves to prepare for the most difficult condition (Monsell, Patterson, Graham, Huges, & Milroy, 1992). They may also adopt a strategy which is viable for both conditions. Thus, it is possible that participants selectively focused on the target in both conditions, leading to similar memory performance for congruent and incongruent targets. We therefore decided to block congruent and incongruent stimuli in a follow-up experiment. We reasoned that in a pure block, focusing attention solely to the target was an optimal strategy for incongruent stimuli but not necessary for congruent stimuli.

Experiment 3

In Experiment 3, we used a similar set-up as in Experiment 2, but we presented the congruent and incongruent stimuli in two separate blocks. We expected better memory performance for incongruent compared to congruent targets. Moreover, in line with our previous experiments, we expected lower memory performance in switch compared to repeat trials. We preregistered Experiment 3 on aspredicted. org.[2]

Method

Participants

Participants were 40 German-speaking volunteers ($M = 23.75$ years, SD 5.56) (13 male and 27 female). They participated for course credits or for a financial compensation (10 CHF), they were recruited by word of mouth. Sample size was based on the same considerations as in Experiment 2. The study was approved by the local ethical committee and all participants gave written consent.

Materials

The materials were the same as in Experiment 2.

Procedure

The procedure of the study phase was the same as in Experiment 2 with the following exceptions. After a brief practice phase with 4 trials, participants performed the study phase in 2 blocks of 16 trials (see Fig. 6). The order of the blocks (congruent, incongruent) was counterbalanced. In both blocks, the instruction was the same, namely to classify the red word and to ignore the green word and to switch task after two trials. Participants were not told that the block was congruent or incongruent, respectively. After completing the task-switching procedure, participants completed an unrelated filler task to counteract potential consequences of the blocked presentation, in particular, differences in the recency effect for congruent and for incongruent stimuli. This task lasted approximately 5 min. Then, free recall was tested as in Experiments 1 and 2.

Statistical analyses

Data preparation was as in Experiment 1. We used a 2 (block order) × 2 (trial type: repeat vs. switch) × 2 (congruent vs. incongruent) ANOVA with repeated measures, the block order was a between-subject factor. For the study phase, we analyzed RTs for correctly classified stimuli and response accuracy. We excluded five participants with an accuracy rate below 0.70. For the test phase, the proportion of recalled words was computed for each participant and for each condition. An alpha level of 0.05 was used for all statistical tests. Effect sizes are expressed as partial η^2 values. As the block order was not significant in all statistical tests, we excluded this factor from further analysis.

Fig. 6 Experiment 3. Top: example of a congruent and an incongruent stimulus. Bottom: trial sequence of the study phase in the incongruent block (the congruent block is not depicted here). The task order was a predictable AABB sequence
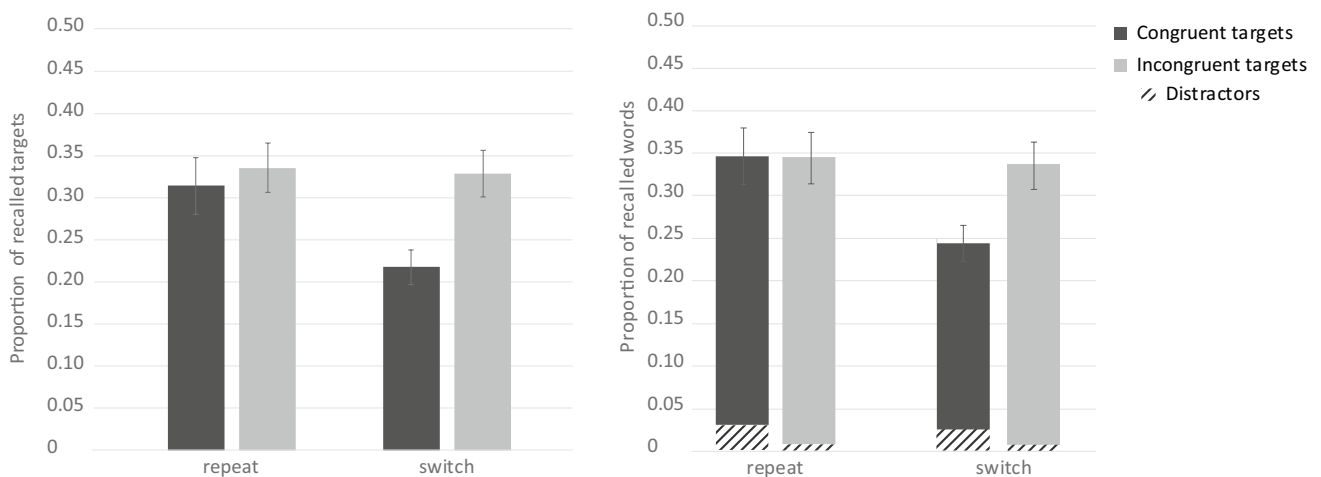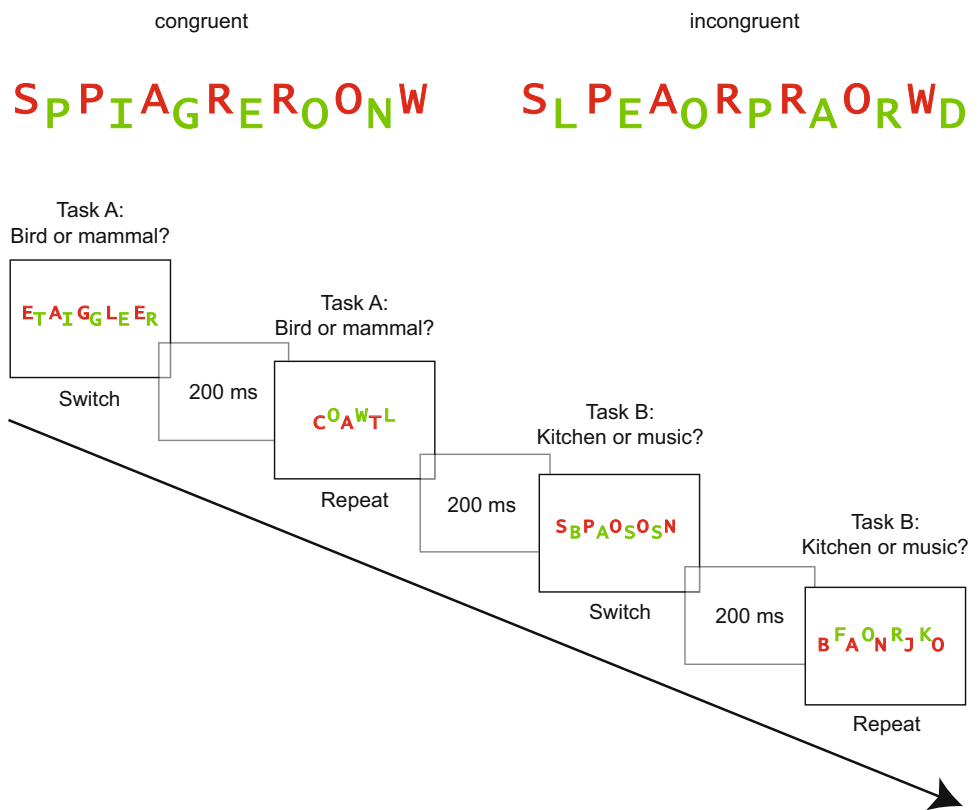
Fig. 7 Experiment 3. Free recall performance for target words as a function of congruency modulated by trial type (left). The shaded areas reflect the distractors and the solid bars the targets (right). Error bars represent standard errors

Results

Study phase

Responses were faster for repeat ($M = 1316$ ms, SE 54 ms) than for switch trials ($M = 1672$ ms, SE 66 ms), $F(1, 34) = 45.94$, $p < 0.001$, $\eta_p^2 = 0.58$, indicating that the expected switch costs occurred. Responses were slightly slower for incongruent ($M = 1535$ ms, SE 65 ms) than for congruent trials ($M = 1452$ ms, SE 60 ms) but this difference was not significant, $F(1, 34) = 1.35$, $p = 0.253$, $\eta_p^2 = 0.04$. The interaction between trial type and congruency was not significant, $F(1, 34) < 1$, $p = 0.547$, $\eta_p^2 = 0.01$.

The same ANOVA on accuracy revealed that performance was high ($M = 0.93$, SE 0.01). Accuracy for repeat ($M = 0.92$, SE 0.02) and switch trials ($M = 0.94$, SE 0.01) did not significantly differ, $F(1, 34) < 1$, $p < 0.444$, $\eta_p^2 = 0.02$. The accuracy did also not differ for incongruent ($M = 0.93$, SE 0.02) and congruent trials ($M = 0.94$, SE 0.01), $F(1, 34) < 1$, $p = 0.601$, $\eta_p^2 = 0.01$, although it was slightly worse for incongruent trials. The interaction between trial type and congruency was not significant, $F(1, 34) < 1$, $p = 0.898$, $\eta_p^2 < 0.01$.

Test phase Overall free recall performance for the targets was $M = 0.30$ (SE 0.02), thus on average, participants correctly recalled 10.2 of a total of 32 target words. The average proportion of intrusions was 1.46 words (SE 0.23). The detailed results are depicted in Fig. 7. An ANOVA with the within-subject factors trial type and congruency revealed that the participants recalled more words from repeat ($M = 0.33$, SE 0.02) than from switch trials ($M = 0.27$, SE 0.02) and this difference reached significance, $F(1, 34) = 5.14$, $p = 0.030$, $\eta_p^2 = 0.13$. Critically, free recall performance for incongruent targets was significantly better ($M = 0.33$, SE 0.02) than for congruent targets ($M = 0.27$, SE 0.02), $F(1, 34) = 4.38$, $p = 0.044$, $\eta_p^2 = 0.11$. The interaction between trial type and congruency was not significant, $F(1, 34) = 1.82$, $p = 0.186$, $\eta_p^2 = 0.05$.

In a next step, we analyzed distractors. An ANOVA with the within-subject factors trial type and congruency revealed that recall did not differ between repeat and switch trials ($M = 0.02$, SE 0.01), $F(1, 34) < 1$, $p = 0.786$, $\eta_p^2 < 0.01$. However, distractors from congruent trials ($M = 0.03$, SE 0.01) were more often recalled than distractors from incongruent trials ($M = 0.01$, SE 0.01), $F(1, 34) = 4.60$, $p = 0.039$, $\eta_p^2 = 0.12$. The interaction between trial type and congruency was not significant, $F(1, 34) < 1$, $p = 0.812$, $\eta_p^2 < 0.01$.

Manipulation check

To check whether performance was indeed slower in the mixed block compared to the pure blocks, we compared RTs of the study phases from Experiment 2 and 3 with a 2 (congruent vs. incongruent) × 2 (Experiment 2 vs. Experiment 3) mixed ANOVA. Repeat and switch conditions were collapsed. RTs in Experiment 3 ($M = 1494$, SE 60) were significantly faster than in Experiment 2 ($M = 1702$, SE 57), $F(1, 72) = 6.31$, $p = 0.014$, $\eta_p^2 = 0.08$. All other effects were not significant, $F(1, 72) < 2.00$, $p > 0.163$, $\eta_p^2 < 0.03$, indicating that the blocked presentation had the expected effect.

Discussion

The aim of Experiment 3 was to investigate the impact of a response-category conflict and task switching on free recall performance. We presented congruent and incongruent stimuli in two separate blocks instead of one mixed block as in Experiment 2. The blocked presentation indeed reduced the control demands as revealed in the manipulation check. This suggests that the blocked presentation of congruent and incongruent stimuli was easier to perform and that resources were available to apply appropriate attentional strategies. Perceptual load was kept constant (two different words were presented in each trial).

Task switching slowed down performance at study and impaired subsequent free recall performance, indicating that it withdrew attention from target encoding. Critically, in Experiment 3, memory performance for incongruent targets was significantly higher than for congruent targets. Thus, the effect of a response-category conflict unfolded due to the opportunity to adopt an appropriate attentional strategy (i.e., focus on targets in the incongruent condition and relaxed focus in the congruent condition) and as a consequence, memory for incongruent target words was enhanced.

Nevertheless, an alternative explanation would be that rather than response-category conflict, the stimulus-category conflict (the co-activation of two different categories) was critical. Specifically, in the congruent condition, both target and distractor were from the same stimulus category and required the same response (e.g., *cat* and *dog*). In contrast, in the incongruent condition, the target and the distractor were from different stimulus categories (e.g. eagle is a bird and tiger a mammal) and they required a different response (i.e., a *l*-key vs. *a*-key response). Therefore, response-category and stimulus-category conflict may be confounded. To test this possibility, in Experiment 4, we kept the response-category conflict constant but varied the stimulus-category conflict by presenting two different words from different categories in the incongruent condition which required the same response (e.g., eagle is a bird and spoon is a kitchen utensil, and both require a *l*-response). If the response-category conflict is indeed critical, then memory performance should not be affected by the stimulus-category conflict. In contrast, if the stimulus-category effect is critical the same memory effect should occur as in Experiment 3.

Experiment 4

Experiment 4 was designed to test whether the presence of a response-category conflict was critical for the memory benefit in Experiment 3 and to rule out the possibility that these results were based on a stimulus-category conflict (i.e., the co-activation of different categories) which was also present

Fig. 8 Experiment 4. Top: example of a congruent and an incongruent stimulus. Bottom: trial sequence of the study phase in the incongruent block (the congruent block is not depicted here). Both words of a trial required the same responses. The task order was a predictable AABB sequence
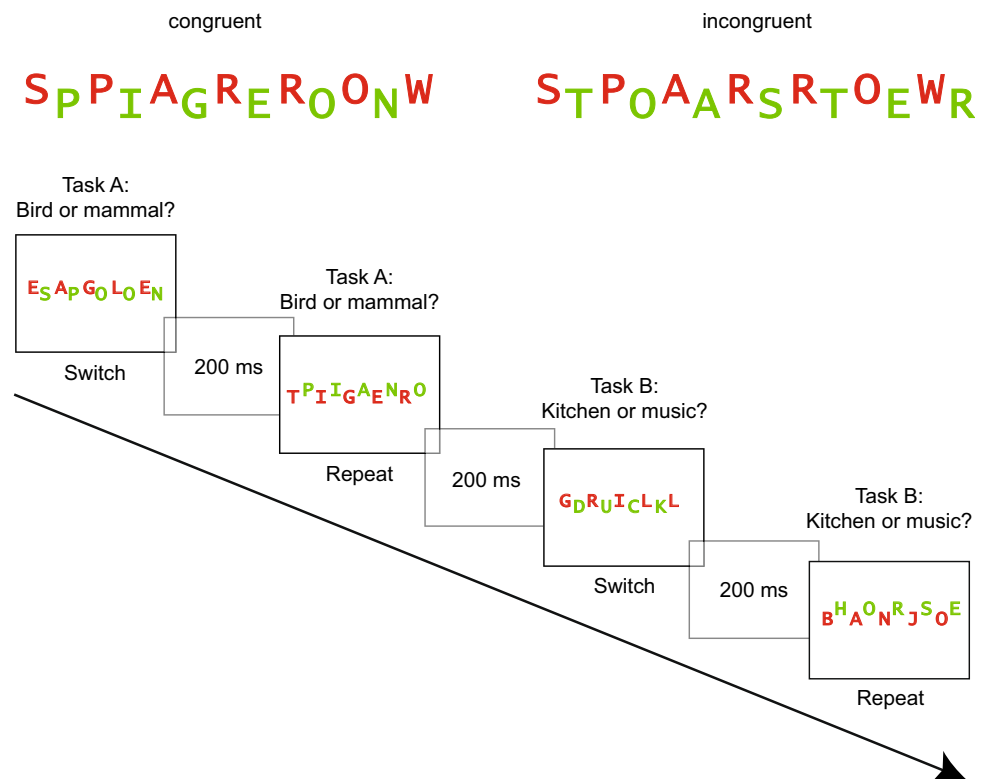
in incongruent trials. Experiment 4 was preregistered on *aspredicted.org*.[3]

Method

Participants

The participants were 40 undergraduate German-speaking students from the University of Bern and they participated for course credits ($M = 22.76$ years, SD 2.89, eight male and 32 female). Sample size was based on the same considerations as in Experiments 2 and 3. The study was approved by the local ethical committee and all participants gave written consent.

Materials

The word materials were the same as in Experiment 2 and 3 but they were differently combined. In the congruent condition, the two words stemmed from the same category. In the incongruent condition, the words stemmed from different categories but they required the same response, thus a pure stimulus-category conflict was induced. Birds were combined with kitchen utensils (both requiring the *l*-key)

and mammals were combined with music instruments (both requiring the *a*-key). An example is presented in Fig. 8. A total of 72 words were used, 18 from each category. They were used for 36 congruent and 36 incongruent stimuli. Four stimuli were used for practice and 32 for the experimental trials.

Procedure

The procedure was the same as in Experiment 3. Congruent and incongruent stimuli were presented in two separate task-switching blocks. A possible trial sequence is depicted in Fig. 8.

Statistical analysis

Data preparation was as in Experiment 3. We used a 2 (block order) × 2 (trial type: repeat vs. switch) × 2 (congruent vs. incongruent) ANOVA with repeated measures, the block order was a between-subject factor.

Results

Study phase

Means of the RTs were faster for repeat ($M = 1550$ ms, SE 88 ms) than for switch trials ($M = 1818$ ms, SE 74 ms), $F(1, 39) = 22.97$, $p < 0.001$, $\eta_p^2 = 0.37$, indicating that the expected
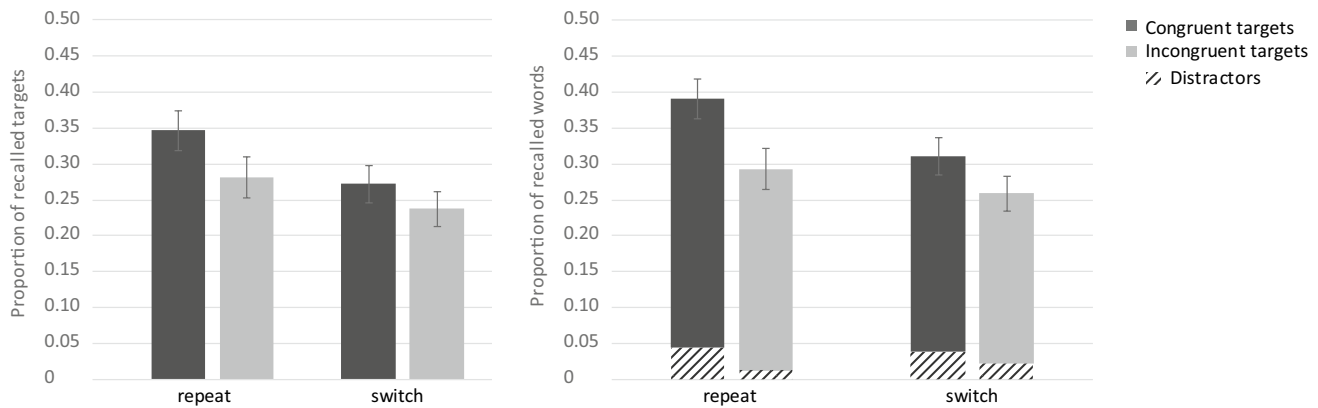
Fig. 9 Experiment 4. Free recall performance for target words as a function of congruency modulated by trial type (left). The shaded areas reflect the distractors and the solid bars the targets (right). Error bars represent standard errors

switch costs occurred. RTs for incongruent ($M = 1711$ ms, SE 82 ms) and congruent stimuli ($M = 1658$ ms, SE 77 ms) did not differ significantly, $F(1, 39) = 1.39$, $p = 0.246$, $\eta_p^2 = 0.03$. The interaction between trial type and congruency was not significant, $F(1, 39) < 1$, $p = 0.783$, $\eta_p^2 < 0.01$.

The analysis of accuracy revealed a main effect of trial type, performance was more accurate for repeat ($M = 0.93$ ms, SE 0.01 ms) than for switch trials ($M = 0.90$ ms, SE 0.01 ms), $F(1, 39) = 5.48$, $p = 0.024$, $\eta_p^2 = 0.12$. Accuracy for congruent stimuli ($M = 0.90$ ms, SE 0.01 ms) was lower than for incongruent stimuli ($M = 0.93$ ms, SE 0.01 ms) but this difference was not significant, $F(1, 39) = 3.66$, $p = 0.063$, $\eta_p^2 = 0.09$. The interaction between trial type and congruency was not significant, $F(1, 39) = 3.47$, $p = 0.070$, $\eta_p^2 = 0.08$.

Test phase

For the test phase, overall free recall performance was $M = 0.28$ (SE 0.02), thus on average, participants correctly recalled 9.2 out of 32 target words. The average proportion of intrusions was 1.65 words (SE 0.32). We analyzed target memory performance with an ANOVA with the same two within-subject variables, trial type and congruency. The results are depicted in Fig. 9. Participants recalled more target words from repeat ($M = 0.32$, SE 0.03) than from switch trials ($M = 0.26$, SE 0.02) and this difference was significant, $F(1, 39) = 4.66$, $p = 0.037$, $\eta_p^2 = 0.11$. As hypothesized, free recall performance for incongruent ($M = 0.26$, SE 0.02) and congruent targets ($M = 0.31$, SE 0.02) did not differ significantly, $F(1, 39) = 2.49$, $p = 0.122$, $\eta_p^2 = 0.06$. The interaction between trial type and congruency was not significant, $F(1, 39) < 1$, $p = 0.415$, $\eta_p^2 = 0.02$.

The null effect of stimulus-category congruency on memory performance indicates that in Experiment 3,

response-category conflict was the cause of the memory effect. Notably, in Experiment 4, numerically, memory was even better for congruent than for incongruent targets. However, as traditional statistics are not suitable to confirm null effects, a Bayesian analysis was conducted (Wagenmakers et al., 2015). The Bayes factor (BF) represents a ratio between the likelihood of two hypotheses. A BF of above 3 indicates evidence for the alternative hypothesis and below 1/3 evidence for the null hypothesis, whereas values ranging from 1/3 to 3 are indicators of inconclusive evidence (Dienes, Coulton, & Heather, 2018). Using JASP (Version 0.8.6), we calculated a Bayesian one-sided paired sample t test on congruency. The null hypothesis represents the possibility that congruent and incongruent targets are equally often recalled. The alternative hypothesis states that incongruent targets are more often recalled than congruent targets. The resulting BF of 0.071 indicates strong evidence for the null hypothesis (i.e., is 14 times more likely than the alternative hypothesis; Jarosz & Wiley, 2014). Accordingly, memory performance for congruent and incongruent targets does not differ and we conclude that the results of Experiment 3 are not confounded by stimulus-category conflict.

In a next step, we analyzed distractors. The ANOVA with the within-subject factors trial type and congruency revealed that a same amount of distractors were recalled from repeat and switch trials ($M = 0.03$, SE 0.01), $F(1, 39) < 1$, $p = 0.881$, $\eta_p^2 < 0.01$. Distractors from congruent trials ($M = 0.04$, SE 0.01) were more often recalled than distractors from incongruent trials ($M = 0.02$, SE 0.01), $F(1, 39) = 6.57$, $p = 0.014$, $\eta_p^2 = 0.14$. The interaction between trial type and congruency was not significant, $F(1, 39) < 1$, $p = 0.405$, $\eta_p^2 = 0.02$. Note, however, that the performance was close to floor and the results of the distractor analysis have to be interpreted cautiously.

Experiment	Congruent condition	Incongruent condition	Effect
Experiment 1	S S P P A A R R R O O W W Target: *l*-key Distractor: *l*-key	S P P I A G R E R O O N W Target: *l*-key Distractor: *l*-key	Perceptual load
Experiment 2 / 3	S P P I A G R E R O O N W Target: *l*-key Distractor: *l*-key	S L P E A O R P R A O R W D Target: *l*-key Distractor: *a*-key	Response-category conflict Stimulus-category conflict
Experiment 4	S P P I A G R E R O O N W Target: *l*-key Distractor: *l*-key	S T P O A A R S R T O E W R Target: *l*-key Distractor: *l*-key	No response-category conflict Stimulus-category conflict

Fig. 10 Depiction of all stimulus conditions with the assigned response keys. Note that congruent and incongruent stimuli were presented in pure blocks in Experiments 3 and 4

Discussion

Experiment 4 was designed to test the assumption that the response-category conflict was critical for a memory benefit in Experiment 3 and not the stimulus-category conflict which was also present in the incongruent condition. To disentangle these possibilities, we varied the stimulus categories in Experiment 4 and eliminated the response-category conflict. In the congruent condition, both words of the stimulus stemmed from the same category, whereas in the incongruent condition, both words stemmed from different categories but required the same response. We hypothesized that both conditions should lead to similar memory performance as no response-category conflict emerged. Moreover, we expected switch-impaired target memory.

The results revealed switch costs in terms of slower task performance and lower accuracy. Again, free recall performance was enhanced for repeat compared to switch trials. However, free recall performance for congruent and incongruent did not differ, indicating that the stimulus-category conflict did not affect memory performance. Thus, co-activation of two incompatible response alternatives was crucial for the memory improvement in Experiment 3. The presence of a response-category conflict signaled a requirement to focus attention solely to the target in order to produce a response that was not conflicting. This resulted in increased attention toward the target which later improved long-term memory. In contrast, in the experiment presented here, such a requirement was not signaled by the incongruent stimuli as target and distractor required the same response.

General discussion

The impact of different types of control demands on memory was investigated in four experiments. At study, we combined a task-switching procedure with different types of incongruent conditions. An overview of all experimental conditions is presented in Fig. 10. In Experiment 1, the control demands were enhanced due to a higher perceptual load. In Experiments 2 and 3, the conflict arose from the co-activation of two words which required different responses (i.e., involved a response-category conflict). In Experiment 4, the conflict arose from the co-activation of two words from different categories (i.e., involved a stimulus-category conflict). The study integrates results from previous studies which showed that different types of control demands can have opposing effects on recognition memory (Krebs et al., 2015; Muhmenthaler & Meier, 2019; Richter & Yeung, 2012, 2015; Rosner, D'Angelo, et al., 2015, Rosner, Davis, et al. 2015; Yue et al., 2013). It also extends the generality of these results using free recall as memory measure. Free recall requires more effortful processing than recognition. More self-initiated processing is involved as no retrieval cues are available and the participants have to initiate appropriate operations more effortful (Craik, 1986). We, therefore, expected stronger effects. Moreover, in the studies by Krebs and colleagues and Richter and Yeung, "remember" responses turned out to be more sensitive than "know" responses for these types of manipulations. As "remember" responses reflect recollection which is similar (albeit not identical) to free recall (Yonelinas, 2002), we reasoned that free recall might represent a

more sensitive measure. In the following sections, the results are discussed by type of conflict.

Implications by conflict type

Perceptual load

In Experiment 1, the incongruent condition consisted of two different words compared to two identical words in the congruent condition. Therefore, the perceptual load was enhanced (Lavie et al., 2009) and this impaired subsequent free recall performance for the target words. It seemed that attention was distracted when the perceptual load was high, which reduced target encoding but facilitated encoding of the unattended distractors. In line with the idea that distractor processing could optimize performance, the results may also rely on a strategical spread of attention to the distractors in the incongruent condition (Ahissar & Hochstein, 2000). However, this is only one interpretation. A limitation was that there was a difference in set size. The words in the congruent condition were presented twice which might have facilitated memory encoding.

Response-category conflict

A response-category involves the co-activation of two incompatible representations which require different responses (Egner et al., 2007). According to the conflict-monitoring model (Botvinick et al., 2001), detecting a conflict serves as an internal signal for reinforcing top-down attention to task-relevant information. Egner and Hirsch (2005) showed that cognitive control mechanisms amplify cortical responses to task-relevant information in response to a response-category conflict. This conflict-driven attentional enhancement leads to higher target memory. In Experiment 3, we replicated previous studies that found enhanced memory performance for incongruent compared to congruent targets (Krebs et al., 2015; Rosner, D'Angelo, et al., 2015). Behaviorally, we assume that attention was strategically focused to the targets when a response-category conflict was present. The incongruent stimuli signaled a requirement to focus attention solely to the target to produce a response that was not conflicting. This is in line with the conflict-monitoring model which suggests that conflict-driven attentional enhancement toward a target leads to successful encoding (Botvinick et al., 2001).

However, enhancing memory by inducing a response-category conflict is not easily achieved. Our experiments revealed that this benefit on memory is reduced when the participants cannot adopt appropriate processing strategies. For example, the mixed presentation of congruent and incongruent trials resulted in a strategy which was viable for both conditions, hence no effect on memory emerged. In a recent study, Ptok, Thomson, Humphreys, and Watter (2019) investigated a response-category conflict in a semantic priming paradigm. Similar to our study, they found a beneficial effect on memory only under specific circumstances. They showed that only tasks that lead to automatic processing result in a beneficial effect on memory, while attention-demanding evaluative processing can eliminate the effect. They concluded that the response-category conflict must elicit control processes which directly focus on the core meaning of the target stimuli. Together, these and our results showed that subtle processing manipulations can influence the effect of a response-category conflict on memory.

Previous research showed that the effect of response-category conflict emerged despite using different tasks at study, namely word reading in Rosner, D'Angelo, et al. (2015), a face-word Stroop task in Krebs et al. (2015), semantic priming in Ptok et al. (2019) and word categorization in our study. This indicates that the effect of response-category conflict is quite robust across different paradigms. In the present study, the effect emerged in combination with task switching. We assume that in an experimental set-up with only one task to perform, stronger effects would materialize. Further research is necessary to specify boundary conditions for this type of conflict.

Stimulus-category conflict

A stimulus-category conflict is defined as the co-activation of two different stimulus categories. This type of conflict was present in the incongruent conditions of the Experiments 2–4. However, in the Experiments 2 and 3, it was confounded with a response-category conflict in the incongruent condition. Therefore, in Experiment 4, we tested the pure effect of a stimulus-category conflict. The results clearly showed that there was a null effect of stimulus-category conflict on memory, in line with the assumption that focusing on the target was of no avail when target and distractor required the same response.

Regarding memory performance for distractors, we found a similar pattern in Experiments 2, 3 and 4. Memory for incongruent distractor words was always lower than memory for congruent distractor words. This can be explained by a strategical spread of attention toward the distractor in the congruent condition at study. As target and distractor stemmed from the same category, spreading attention toward the distractor could help to optimize performance. However, this finding might also be explained by more memory intrusion from the same category (i.e. congruent distractors) than from a different category (i.e. incongruent distractors) at retrieval by spreading activation throughout the semantic network (Anderson, 1983). Thus, the difference in recalled distractors might reflect a retrieval effect and not necessarily

an encoding effect. To decide between these possibilities, further research is necessary.

Task switching

All experiments replicated that task switching impairs encoding of task-relevant information (Muhmenthaler & Meier, 2019; Reynolds et al., 2004; Richter & Yeung, 2012, 2015). Task switching withdraws attention from target encoding in order to enable operations on task level. This also allows distractor intrusion by affecting stimulus-processing priorities (Lavie et al., 2004; Richter & Yeung, 2012, 2015), see Experiment 1, Fig. 3. In other words, performance is less shielded against distraction when participants have to switch task (Dreisbach & Wenke, 2011), and this results in less successful target encoding. Richter and Yeung (2015) manipulated the control demands in a task-switching procedure by varying the preparation time, by voluntary and involuntary switching and by rewards. The results revealed that these manipulations led to efficient top-down control, resulting in enhanced target memory and less distractor intrusions. Together, larger control demands as produced by task switching or other control manipulations reduce encoding of task-relevant information but they facilitate encoding of task-irrelevant information. That is, they lead to a "broadening" of cognitive control.

Conclusion

The main goal of the study was to produce control-enhanced and control-impaired target memory within the same experiment. Task switching was combined with different types of congruency manipulations. We present the first evidence for switch-impaired and conflict-enhanced memory performance within one experiment. While task switching consistently impaired target memory in all experiments, response-category conflict had a weaker effect and it emerged only when appropriate strategies could be applied. Stimulus-category conflict did not affect memory, indicating that the co-activation of two response alternatives is critical for a memory benefit (Botvinick et al., 2001; Egner et al., 2007).

Opposing effects on memory reflect that the allocation of attention at study is crucial for later memory performance. Attention toward the targets is impaired when the control demands are enhanced due task switching requirements or due to a high perceptual load. These conditions withdraw attention from target processing, resulting in decreased target memory but also in enhanced distractor encoding. In contrast, the presence of a response-category conflict leads to focused attention toward the target resulting in increased target memory. Cognitive control mechanisms seem to amplify cortical responses to task-relevant information, and

as a consequence, subsequent target memory is enhanced (Egner & Hirsch, 2005). In conclusion, our results demonstrate that the specific type of control demands regulate the competition between encoding of task-relevant and task-irrelevant information which can produce opposing subsequent memory effects.

References

Ahissar, M., & Hochstein, S. (2000). The spread of attention and learning in feature search: Effects of target distribution and task difficulty. *Vision Research, 40,* 1349–1364.

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Conscious and nonconscious information processing: Attention and performance XV* (pp. 421–452). Cambridge, MA: MIT Press.

Allport, A., & Wylie, G. (1999). Task switching: Positive and negative priming of task-set. In G. W. Humphreys, J. Duncan, & A. M. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 273–296). Oxford: Oxford University Press.

Anderson, J. R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior, 22,* 1–33.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624–652. https://doi.org/10.1037/0033-295X.108.3.624.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010.

Chiu, Y. C., & Egner, T. (2016). Distractor-relevance determines whether task-switching enhances or impairs distractor memory. *Journal of Experimental Psychology: Human Perception and Performance, 42*(1), 1–5. https://doi.org/10.1037/xhp0000181.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97,* 332–361.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capabilities: Mechanisms and performances* (pp. 409–422). North Holland: Elsevier Science Publishers.

Davis, H., Rosner, T. M., D'Angelo, M. C., MacLellan, E., & Milliken, B. (2019). Selective attention effects on recognition: The roles of list context and perceptual difficulty. *Psychological Research.* https://doi.org/10.1007/s00426-019-01153-x.

Dienes, Z., Coulton, S., & Heather, N. (2018). Using Bayes factors to evaluate evidence for no effect: Examples from the SIPS project. *Addiction, 113*(2), 240–246.

Dreisbach, G., & Wenke, D. (2011). The shielding function of task sets and its relaxation during task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 1540–1546. https://doi.org/10.1037/a0024077.

Duncan, J. (1977). Response selection rules in spatial choice reaction tasks'. In S. Dornik (Ed.), *Attention and performance VI*. Hillsdale, NJ: Erlbaum.

Egner, T., Delano, M., & Hirsch, J. (2007). Separate conflict-specific cognitive control mechanisms in the human brain. *NeuroImage., 35,* 940–948. https://doi.org/10.1016/j.neuroimage.2006.11.061.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8,* 1784–1790. https://doi.org/10.1038/nn1594.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/bf03193146.

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 4,* 480–506.

Jarosz, A. F., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *The Journal of Problem Solving, 7*(1), 2.

Jersild, A. T. (1927). Mental set and shift. *Archives of Psychology, 89,* 5–82.

Kiesel, A., Wendt, M., & Peters, A. (2007). Task switching: On the origin of response congruency effects. *Psychological Research, 71*(2), 117–125. https://doi.org/10.1007/s00426-005-0004-8.

Krebs, R. M., Boehler, C. N., De Belder, M., & Egner, T. (2015). Neural conflict-control mechanisms improve memory for target stimuli. *Cerebral Cortex, 3,* 833–843. https://doi.org/10.1093/cercor/bht283.

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133,* 339–354. https://doi.org/10.1037/0096-3445.133.3.339.

Lavie, N., Lin, Z., Zokaei, N., & Thoma, V. (2009). The role of perceptual load in object recognition. *Journal of Experimental Psychology: Human Perception and Performance, 35*(5), 1346–1358. https://doi.org/10.1037/a0016454.

Los, S. A. (1994). Procedural differences in processing intact and degraded stimuli. *Memory and Cognition, 22*(2), 145–156.

Los, S. A. (1999). Identifying stimuli of different perceptual categories in pure and mixed blocks of trials: Evidence for stimulus-driven switch costs. *Acta Psychologica, 103,* 173–205.

Mayr, U., & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129,* 4–26. https://doi.org/10.1037/0096-3445.129.1.4.

Meier, B., & Rey-Mermet, A. (2012). Beyond feature binding: Interference from episodic context binding creates the bivalency effect in task-switching. *Frontiers in Psychology, 3,* 386. https://doi.org/10.3389/fpsyg.2012.00386.

Meier, B., Woodward, T. S., Rey-Mermet, A., & Graf, P. (2009). The bivalency effect in task switching: General and enduring. *Canadian Journal of Experimental Psychology, 63,* 201–210.

Meiran, N. (2000). Modeling cognitive control in task-switching. *Psychological Research, 63*(3–4), 234–249.

Meiran, N., & Kessler, Y. (2008). The task rule congruency effect in task switching reflects activated long-term memory. *Journal of Experimental Psychology: Human Perception and Performance, 34*(1), 137–157. https://doi.org/10.1037/0096-1523.34.1.137.

Milliken, B., & Joordens, S. (1996). Negative priming without overt prime selection. *Canadian Journal of Experimental Psychology, 50*(4), 333–346.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7,* 134–140.

Monsell, S., Patterson, K. E., Graham, A., Huges, C. H., & Milroy, R. (1992). Lexical and sublexical translation from spelling to sound: Strategic anticipation of lexical status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 452–467.

Muhmenthaler, M. C., & Meier, B. (2019). Task switching hurts memory encoding. *Experimental Psychology.* https://doi.org/10.1027/1618-3169/a000431.

Ortiz-Tudela, J., Milliken, B., Botta, F., LaPointe, M., & Lupiañez, J. (2017). A cow on the prairie vs. a cow on the street: Long-term consequences of semantic conflict on episodic encoding. *Psychological Research, 81*(6), 1264–1275. https://doi.org/10.1007/s00426-016-0805-y.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Ptok, M., Thomson, S. J., Humphreys, K. R., & Watter, S. (2019). Congruency encoding effects on recognition memory: A stage-specific account of desirable difficulty. *Frontiers in Psychology, 10,* e858. https://doi.org/10.3389/fpsyg.2019.00858.

Reynolds, J. R., Donaldson, D. I., Wagner, A. D., & Braver, T. S. (2004). Item- and task-level processes in the left inferior prefrontal cortex: Positive and negative correlates of encoding. *NeuroImage, 21,* 1472–1483. https://doi.org/10.1016/j.neuroimage.2003.10.033.

Richter, F. R., & Yeung, N. (2012). Memory and cognitive control in task switching. *Psychological Science, 23,* 1256–1263. https://doi.org/10.1177/0956797612444613.

Richter, F. R., & Yeung, N. (2015). Corresponding influences of top-down control on task switching and long-term memory. *The Quarterly Journal of Experimental Psychology, 68,* 1124–1147. https://doi.org/10.1080/17470218.2014.976579.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*(2), 207–231.

Rosner, T. M., D'Angelo, M. C., MacLellan, E., & Milliken, B. (2015a). Selective attention and recognition: Effects of congruence on episodic learning. *Psychological Research, 79*(3), 411–424. https://doi.org/10.1007/s00426-014-0572-6.

Rosner, T. M., Davis, H., & Milliken, B. (2015b). Perceptual blurring and recognition memory: A desirable difficulty effect revealed. *Acta Psychologica, 160,* 11–22. https://doi.org/10.1016/j.actpsy.2015.06.006.

Wagenmakers, E.-J., Verhagen, A. J., Ly, A., Matzke, D., Steingroever, H., Rouder, J. N., et al. (2015). The need for Bayesian hypothesis testing in psychological science. In S. O. Lilienfeld & I. Waldman

(Eds.), *Psychological science under scrutiny: Recent challenges and proposed solutions* (pp. 123–138). Hoboken, NJ: Wiley.

Woodward, T. S., Meier, B., Tipper, C., & Graf, P. (2003). Bivalency is costly: Bivalent stimuli elicit cautious responding. *Experimental Psychology, 50,* 233–238.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46*(3), 441–517. https://doi.org/10.1006/jmla.2002.2864.

Yue, C. L., Castel, A. D., & Bjork, R. A. (2013). When disfluency is—and is not—a desirable difficulty: The influence of typeface clarity on metacognitive judgments and memory. *Memory & Cognition, 41*(2), 229–241. https://doi.org/10.3758/s13421-012-0255-8.

Response Congruency Affects Delayed Memory Performance

Michèle C. Muhmenthaler & Beat Meier

University of Bern

Author Note

Michèle C. Muhmenthaler, Institute of Psychology, University of Bern.

Correspondence concerning this article should be addressed to Michèle Muhmenthaler

or Beat Meier, Institute of Psychologie, Fabrikstrasse 8, 3012 Bern.

E-mail: michele.muhmenthaler@psy.unibe.ch or beat.meier@psy.unibe.ch

Abstract

Events that are congruent with one's knowledge lead to better memory than those which are not, and this effect is stronger after a delay than after immediate testing. However, it is not clear whether *response* congruent events also can also enhance memory. The goal of the current study was to investigate this question. We present two experiments in which participants switched between two picture classification tasks with the same set of response keys for both tasks thereby creating response congruent and response incongruent stimuli. Participants completed a surprise recognition memory test either immediately or after a one-week delay. The results revealed that response congruent stimuli led to better memory performance than response incongruent stimuli, but this effect occurred only after the one-week interval. Thus, experimentally induced congruency resulted in a novel (response) schema which facilitated consolidation and enhanced delayed memory performance.

Keywords: bivalent stimuli, task-switching, long-term memory, congruency, consolidation, neural replay

Response Congruency Affects Delayed Memory Performance

Research consistently shows that events which are congruent with existing knowledge are better remembered than incongruent events (Cortese, Khanna, & Von Nordheim, 2019). However, it is not clear whether *response* congruent events also can also enhance memory. Response congruency can be induced by asking participants to switch between two tasks which require the same set of responses. Thus, categories are linked together during task switching and create a novel (response) schema. The goal of the current study was to investigate whether response congruency can foster memory through the formation of a novel schema.

Schemata, that is, networks of interconnected neocortical representations of prior knowledge, are established in early childhood and continue to develop throughout life (Bartlett, 1935; Piaget, 1952). They exert powerful influences over how events are perceived and interpreted (Gilboa & Marlatte, 2017). Critically, information that is congruent with prior knowledge is better remembered than incongruent information and this effect is stronger after a delay (Hennies, Lambon Ralph, Kempkes, Cousins, & Lewis, 2016; van Kesteren, Rijpkema, Ruiter, & Fernández, 2013b). The schema theory of memory consolidation explains this effect with an accelerated integration of new information into a pre-existing schema represented in cortical areas, a process that is mediated by the medial prefrontal cortex (Durrant, Cairney, McDermott, & Lewis, 2015; van Kesteren et al., 2013a). There is evidence that the consolidation of schema-congruent memories is associated with rapid eye movement (REM) sleep rather than slow wave sleep (Boyce, Glasgow, Williams, & Adamantidis, 2016; Durrant et al., 2015; Stickgold, Whidbee, Schirmer, Patel, & Hobson, 2000).

Evidence for the schema theory of memory consolidation was for example provided by van Kesteren and colleagues (2013b). In their experiment, the participants had to study simultaneously presented combinations of visual motifs, visual object words and tactile fabric

samples which were either congruent (e.g., *jacket* and *leather*) or incongruent (e.g., *umbrella* and *lace*), then they were tested by a recognition test for the motifs either directly after encoding, after one day or after two days. The results showed a congruency effect which increased with time. In a related study by Hennies et al. (2016), participants established a novel schema over six sessions during two weeks. Then, they learned new facts which were related or completely unrelated to the schema in two additional sessions separated by a night of sleep. Directly after the second additional session memory for all facts was tested in a two-alternative task. The results revealed better memory for schema congruent information and this effect became stronger overnight. Moreover, sleep spindle density predicted an increase of the schema benefit across the retention interval, emphasizing the crucial role of memory reactivation during sleep (Diekelmann & Born, 2010; Dudai, Karni, & Born, 2015).

Together, there is solid evidence for this memory congruency effect (Durrant et al., 2015; Hennies et al., 2016; van Kesteren et al., 2013b). However, in all previous studies, congruency was related to prior knowledge, that is, on earlier acquired schemata. In contrast, in the current study, a novel schema was created "*online*" during the study phase. Specifically, we used two picture categorization tasks with bivalent stimuli, that is stimuli which can be processed in both tasks. Moreover, we used the same set of response keys in both tasks, thus response congruency was induced. The participants had to classify the pictures alternately as *smaller* or *bigger than a soccer ball* and as *living* or *non-living* in a task-switching paradigm (cf. Muhmenthaler & Meier, 2019). Thus, two categories which required the same response were linked together to one response category (e.g., *bigger than a soccer ball* and *living* both requiring the *a*-key), see Figure 1. Although there was pre-existing knowledge for the single categories (we have a schema for what is living), a novel schema for the linked categories was directly created through the ongoing task (Bartlett, 1935). The aim of the study was to investigate whether such a novel response schema can foster memory formation. We

hypothesized that response congruent stimuli are better remembered than response

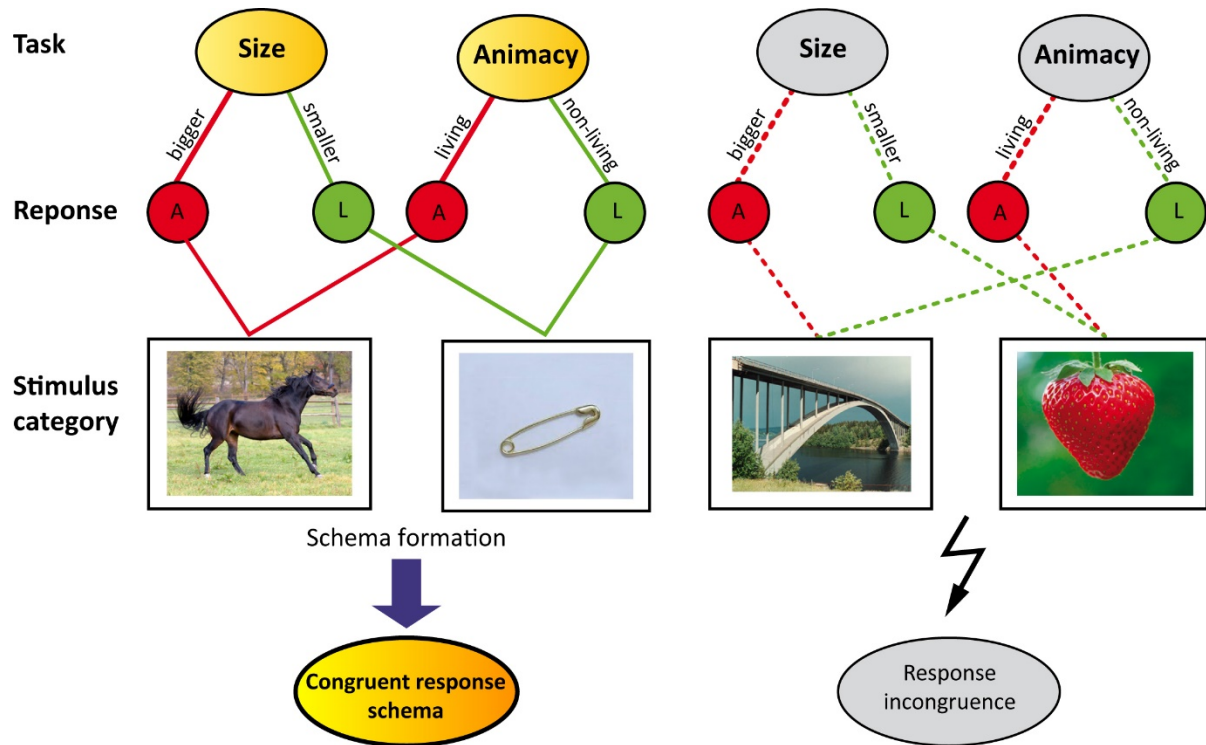incongruent stimuli and that this effect is more pronounced after one week.

Figure 1. Depiction of schema formation. Left part: two categories requiring the same

responses in both tasks are linked together to one response category. Right part: no stimulus

categories are linked due to different responses in both tasks.

Experiment 1

Method

Participants. The participants were 32 undergraduate students (8 male and 24 female)

from the University of Bern. They participated in the study for course credits and gave written

consent. The age ranged from 19 to 44 years ($M = 23.01$, $SD = 5.40$). In an a priori power

analyses we computed the sample size as a function of the required power level, the

significance level and the population effect size which we expected (Faul, Erdfelder, Lang, &

Buchner, 2007). We used an expected effect size for response congruency of $f = 0.25$, based

on previous results (cf. Muhmenthaler & Meier, 2019), a significance level of .05 and .95 as

power level. The analysis computed 36 participants as an optimal sample size.

Material. For the experimental trials, a total of 128 colored photographs were used

which were collected from a web search. They could unambiguously be classified both as

smaller-or-bigger than a soccer ball and as living or non-living. Thus, four stimulus categories

were created. Stimuli which were *bigger than a soccer ball* and *living* (e.g. an elephant) as

well as stimuli which were *smaller than a soccer ball* and *non-living* (e.g. a cup) were

response congruent, they required the same response in both tasks. Stimuli which were *bigger*

than a soccer ball and *non-living* (e.g. a car) as well as stimuli which were *smaller than a*

soccer ball and *living* (e.g. a fly) were response incongruent, they required different responses

in both tasks. Each stimulus category involved 32 stimuli., thus half of the stimuli were

response congruent and the other half response incongruent respectively. The stimuli were

arranged in separate lists of 64 pictures, counterbalanced across category and trial type (repeat

vs. switch), such that each stimulus occurred equally often in the repeat and switch condition

and in each task. One of the lists was used in the study phase. In the first memory test, 32

stimuli of this list were used again (old) and 32 new stimuli of the other list as lures. In the

second memory test, the remaining stimuli were shown from both lists (32 old, 32 new). The

lists were counterbalanced across participants, each stimulus appeared equally often in the

study phase and in both test phases. Eight additional photographs (two per stimulus category)

were used for practice.

Procedure. Participants were tested individually in a computer laboratory. In the

study phase, they were instructed to categorize the stimuli as fast and as accurately as possible

and to switch between the two tasks. Participants had to perform the size task when the

stimulus appeared in the upper part of the screen, and to perform the animacy task when it

appeared in the lower part. The stimuli were presented clockwise, beginning in the upper half

on the left, which led to a predictable AABB sequence of the two tasks, see Figure 2.

Participants had to press the *a*-key when an object was *bigger than a soccer ball* or *living*, and the *l*-key when the object was *smaller than a soccer ball* or *non-living*. The stimuli were presented until a response key was pressed, then the next stimulus was presented after a response-stimulus interval of 200 ms. The stimuli were presented randomized, each task twice in succession. After a brief practice phase with eight trials, participants performed the study phase with 64 trials. Following the study phase, participants completed an unrelated filler task which lasted approximately 15 minutes, the main purpose was to create a filled retention interval.

Then, recognition memory was tested for half of the stimuli which have been shown in the study phase and for the same number of lures. Thus, the recognition test involved 64 experimental trials. Participants had to indicate whether they had seen a stimulus before by pressing the *j*-key for "old" stimuli and by pressing the *n*-key for "new" stimuli. The stimuli appeared in randomized order with a response stimulus interval of 200 ms. The entire experiment lasted about 25 min. Then, the participants were instructed to come again in a week, they were not told that their memory will be tested again. In the second session, they were tested for the other half of the old stimuli and for 32 new stimuli.
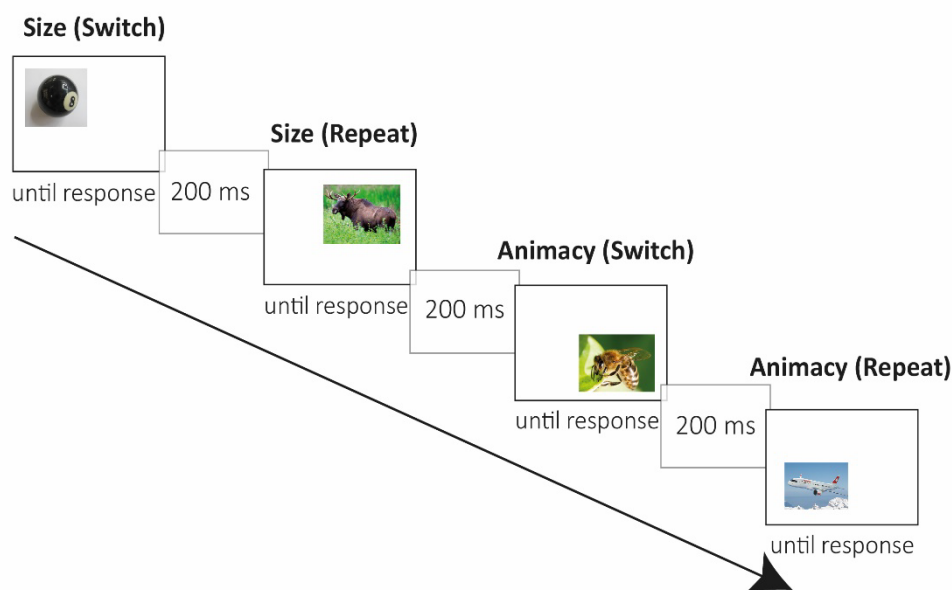

Figure 2. Predictable AABB study trial sequence. The stimuli were presented clockwise.

Statistical analyses. Memory performance was analyzed with an 2 x 2 x 2 ANOVA with the three within-subject factors test time (immediately, delayed) x response congruency (congruent; incongruent) x task switching (repeat, switch). As dependent variable, we used hit rates (correctly named old items). The reason is that it was not possible to assign the false alarm rates to repeat or switch trials. The false alarms for congruent and incongruent stimuli were separately analyzed with a two-paired sample t test. An alpha level of 0.05 was used. Effect sizes are expressed as partial η^2 values.

Results

The ANOVA with the factors test time (immediately, delayed), response congruency (congruent, incongruent) and task switching (repeat, switch) revealed that memory performance was unsurprisingly better in the immediate test ($M = .87$, $SE = .02$) than in the delayed test ($M = .34$, $SE = .03$), $F(1,31) = 295.57$, $p < .001$, $\eta_p^2 = .91$. The detailed results are depicted in Figure 3. Overall, memory performance was significantly better for response congruent ($M = .62$, $SE = .02$) than for response incongruent stimuli ($M = .58$, $SE = .02$), $F(1,31) = 7.32$, $p = .011$, $\eta_p^2 = .19$. The interaction between test time and response congruency also reached almost significance, $F(1,31) = 3.80$, $p = .061$, $\eta_p^2 = .11$. Planned contrasts revealed that memory performance for response congruent ($M = .87$, $SE = .02$) and response incongruent stimuli ($M = .86$, $SE = .02$) did not differ significantly in the immediate test $t(31) < 1$, $p = .742$, $d = 0.06$, whereas in the delayed test, memory performance was significantly better for response congruent ($M = .38$, $SE = .03$) than for response incongruent stimuli ($M = .30$, $SE = .03$), $t(31) = 2.77$, $p = .009$, $d = 0.49$. These results suggest that a novel schema was established during the study phase which enhanced memory performance after consolidation.

The overall main effect of task switching was not significant, $F(1,31) < 1$, $p = .346$, $\eta_p^2 = .03$. However, the interaction between test time and task switching was almost

significant, $F(1,31) = 3.37$, $p = .076$, $\eta_p^2 = .10$. Planned contrasts revealed that in the

immediate test, memory performance was better in repeat ($M = .89$, $SE = .02$) than in switch

trials ($M = .85$, $SE = .02$) ($t(31) = 2.63$, $p = .013$ $d = 0.46$), whereas memory performance for

repeat ($M = .33$, $SE = .03$) and switch trials ($M = .34$, $SE = .03$) was similar in the delayed test

$t(31) < 1$, $p = .766$, $d = 0.05$. The results suggest that due to greater control demands in switch

trials, attention was withdrawn from target encoding which resulted in lower memory

performance (Muhmenthaler & Meier, 2019; Richter & Yeung, 2012). However, the impact

of task switching on memory washed out over time. Neither the interaction between response

congruency and task switching was significant nor the three-way interaction, $F(1,31) < 2.26$,

$p > .143$, $\eta_p^2 < .07$.

The false alarm rate did not differ in the immediate ($M = .10$, $SE = .01$) and in the

delayed test ($M = .09$, $SE = .01$), $F(1,31) < 1$, $p = .422$, $\eta_p^2 = .02$. Neither the false alarm rate

for response congruent ($M = .11$, $SE = .01$) and response incongruent stimuli ($M = .09$, $SE =$

$.02$) ($F(1,31) = 2.361$, $p = .135$, $\eta_p^2 = .07$), nor the interaction between test time and false

alarm rate did significantly differ, $F(1,31) < 1$, $p = .555$, $\eta_p^2 = .01$.
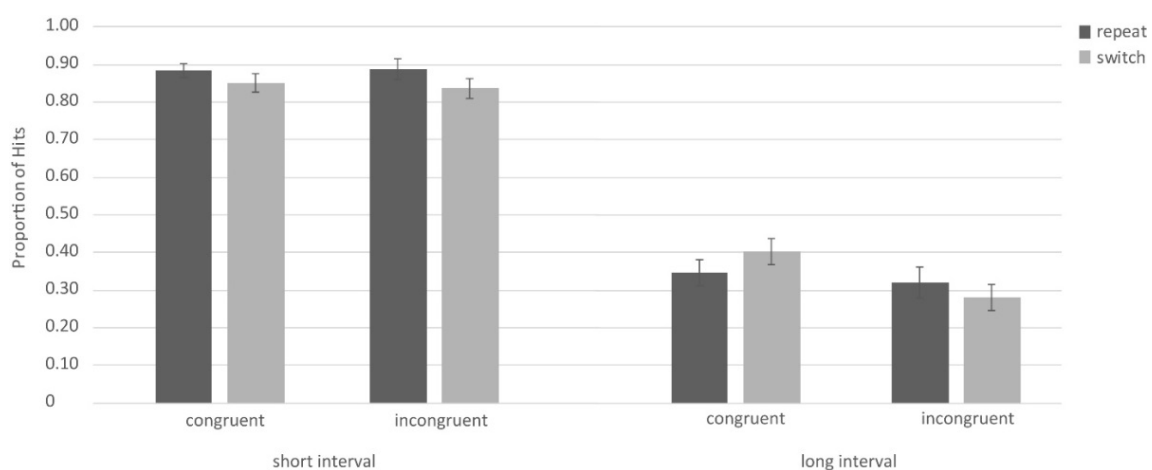
Figure 3. Memory performance in Experiment 1. Mean proportion of hits as a function of

response congruency, modulated by task switching. The error bars represent the standard

error.

Experiment 2

In Experiment 2, we wanted to replicate our findings. We conducted the same experiment, but the participants had to perform the recognition test only after the long study-test interval of a week. This design helped us to boost power, the amount of trials in the recognition test was doubled. Moreover, we reasoned that one single test phase might be more suited to investigate delayed memory effects, as possible carry over effects are eliminated. We expected a stronger effect for response congruency than in Experiment 1.

Method

Participants. The participants were 40 undergraduate students (5 male and 35 female) from the University of Bern. They participated in the study for course credits and gave written consent. The age ranged from 18 to 27 years ($M = 22.94$, $SD = 2.20$). Sample size was based on the same considerations as in Experiment 1.

Materials and Procedure. The experiment was similar to Experiment 1, with the only exception that the participants were tested for their memory only once after one week. After the study phase, the participants were told to come again in one week at the same time, they were not told that they had to memorize the stimuli.

Statistical analyses. The proportion of hits were analyzed using a 2 (congruent, incongruent) x 2 (repeat, switch) ANOVA with repeated measures. The false alarms for congruent and incongruent stimuli were separately analyzed with a two-paired sample t test. An alpha level of 0.05 was used for all analyses. Effect sizes are expressed as partial η^2 values.

Results

The hit rate (correct "old" responses) was 46% and the false-alarm rate was 17%. A paired-sample t test revealed no significant difference between the false alarm rate of response congruent ($M = .17$, $SE = .02$) and response incongruent stimuli ($M = .16$, $SE = .02$), $t(39) < 1$, $p = .550$, $d = 0.10$. Memory performance was further analyzed using a 2 x 2 ANOVA with the

within-subject factors response congruency and task switching. The detailed results are

depicted in Figure 4. Critically, memory performance for response congruent stimuli (M = .49

, SE = .03) was substantially better than for response incongruent stimuli (M = .40, SE = .03),

$F(1, 39) = 29.25$, $p < .001$, $\eta_p^2 = .43$. The results suggest that experimentally induced

congruency facilitated memory formation with consolidation.

Memory performance for repeat (M = .46, SE = .03) and switch stimuli (M = .44, SE =

.02) did not significantly differ, $F(1, 39) = 1.90$, $p = .176$, $\eta_p^2 = .05$. Although memory was

numerically lower for switch trials, task switching had no effect on memory performance,

indicating that the detrimental effect of task switching washed out with time. The interaction

between response congruency and task switching was also not significant, $F(1, 39) < 1$, $p =$

.967, $\eta_p^2 < .01$.
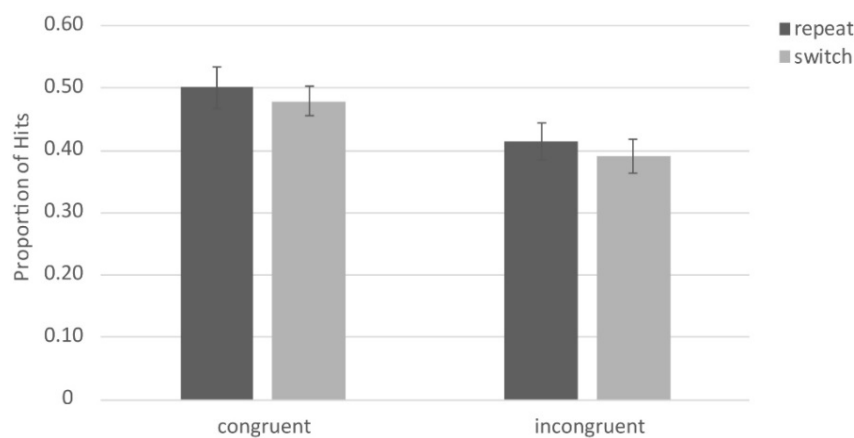
Figure 4. Memory performance in Experiment 2. Mean proportion of hits as a function of

response congruency, modulated by task switching. The error bars represent the standard

error.

Discussion

Previous research has shown that events those items match along a specific dimension

lead to a congruency effect on memory, that is, better memory for congruent than incongruent

events. This effect was explained with pre-existing schemata that foster memory formation for

new related information (Cortese et al., 2019). Moreover, previous research has shown that the congruency effect is stronger after a delay than after immediate testing (Hennies et al., 2016; van Kesteren et al., 2013b). In the current study, we investigated whether *response congruency* can also produce this effect. We present a novel paradigm in which a schema is acquired *online,* that is, during the study phase. Response congruency was induced with stimuli that required the same response in two tasks of a task-switching procedure (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). In two experiments, participants had to switch between two picture classification tasks with response congruent and response incongruent stimuli, then recognition memory was tested either immediately or after one week. We predicted that response congruent stimuli would enhance memory due to *online* schema formation. We further predicted that this effect would increase with time due to post-learning processes which preferentially and rapidly consolidate schema congruent information (Durrant et al., 2015; van Kesteren et al., 2013b). The results showed no effect of response congruency in the immediate memory test. However, it emerged after one week. Thus, consolidation processes were necessary to produce a beneficial effect on memory (Durrant et al., 2015; Hennies et al., 2016; van Kesteren et al., 2013b).

        We provide first evidence for a schema effect which was not based on prior knowledge. In contrast, the schema was directly established during performing a study phase. Thus, the processing of response congruent stimuli resulted in a "transient" schema which enhanced delayed memory. The idea of a transient schema is not new. According to Bartlett (1935), a schema is a dynamic and continuously-evolving pattern which is constructed directly by the ongoing activity (Iran-Nejad & Winsler, 2000). Bartlett described such a *schema-of-the moment* as an ongoing organization which lasts as long as it continues to be created and upheld. In the experiments presented here, we present evidence for such a *schema-of-the-moment*.

On a neural level, new schema formation could rely on the reactivation of newly learned memories during slow wave sleep. Lewis and Durrant (2011) postulated a model under which the overlapping replay of related memories selectively strengthens shared elements. The overlapping replay could serve to strengthen areas of commonality, that is, congruent information. In combination with the synaptic downscaling that occurs during slow wave sleep (Tononi & Cirelli, 2003), such overlap could lead to the gradual formation of new schemata through repeated reactivation of memories. Together, it is possible that slow wave sleep which occurs earlier in the night is involved in forming a new schema and REM sleep occurring later in the same night is involved in integrating the new schema into neocortical networks in a two-step process (Durrant et al., 2015; Stickgold et al., 2000). Previous research has provided evidence that REM sleep rather than slow wave sleep is engaged in the consolidation of schema congruent information (Boyce et al., 2016).

Human neuroimaging studies showed decreased hippocampal involvement along with enhanced medial prefrontal cortex activity during the integration of new congruent information into a pre-existing schema This is evidence that congruent information is consolidated in neocortical areas, a process which is faster than standard hippocampus-driven consolidation (van Kesteren et al., 2013a). Also animal research showed that consolidation can occur quickly if an associative schema into which new information is incorporated has previously been created (Tse et al., 2007). In these studies with rats, the authors showed that newly learned paired associates which were congruent with a previously learned spatial schema became hippocampally-independent and consolidated within 48 hours. Although not having direct evidence, we assume that schema consolidation was based on similar processes in our experiments.

Our experiments also replicated that task switching impairs immediate memory performance in line with previous studies (Muhmenthaler & Meier, 2019; Richter & Yeung, 2012). The control demands in switch compared to repeat trials were larger due to the

requirement to switch task (Rogers & Monsell, 1995) and due to the requirement to select the appropriate task (Allport et al., 1994; Woodward, Meier, Tipper, & Graf, 2003). These control demands in switch trials withdrew attention from target encoding and resulted in impaired memory for switch stimuli. This effect washed out over time.

Conclusion

The present study provides evidence for a congruency effect on memory produced by *response congruent* stimuli. The results suggest that an online created novel schema can foster memory formation. As this effect was not apparent directly after encoding, specific processes of consolidation, as the neural replay during sleep, was critical to produce the beneficial effect on memory.

Ethic statement

This study was approved by the Ethics Committee of the Faculty of Human Sciences at the University of Bern and followed the guidelines of the Declaration of Helsinki.. Procedures were executed in conformity with the approved guidelines.

Author Contributions

M.C. Muhmenthaler and B. Meier designed the experiments. M. C. Muhmenthaler conducted the experiments and analzyed the data. Both authors wrote the manuscript and approved the final manuscript for submission.

ORCID iD

Michèle C. Muhmenthaler: https://orcid.org/0000-0002-7376-1164

Acknowledgments

Declaration of Conflicting Interests

The authors declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

Funding

Open Practices Statement

Neither of the experiments reported in this article was formally preregistered. Neither the data nor the materials have been made available on a permanent third-party archive; requests for the data or materials can be sent via email to the lead author at michele.muhmenthaler@psy.unibe.ch

References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic

control of tasks. In C. Umilta & M. Moscovitch (Eds.), Attention and performance XV

(pp. 421–452). *Cambridge, MA: MIT Press.*

Bartlett, F. C. (1935). Remembering. *Scientia, 52,* 221-226.

Boyce, R., Glasgow, S. D., Williams, S., & Adamantidis, A. (2016). Causal evidence for the

role of REM sleep theta rhythm in contextual memory consolidation. *Science,*

352(6287), 812–816.

Cortese, M. J., Khanna, M. M., & Von Nordheim, D. (2019). Incidental memory for colour

word associates processed in colour naming and reading aloud tasks: is a blue ocean

more memorable than a yellow one? *Memory, 27*(7), 924-930.

doi:10.1080/09658211.2019.1607877

Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews*

Neuroscience, 11, 114 –126.

Dudai, Y., Karni, A., & Born, J. (2015). The consolidation and transformation of memory.

Neuron, 88, 20-32. doi:10.1016/j.neuron.2015.09.004

Durrant, S. J., Cairney, S. A., McDermott, C., & Lewis, P. A. (2015). Schema-conformant

memories are preferentially consolidated during REM sleep. *Neurobiology of*

Learning and Memory, 122, 41–50

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical

power analysis program for the social, behavioral, and biomedical sciences. *Behavior*

Research Methods, 39(2), 175-191. doi:10.3758/bf03193146.

Gilboa, A., & Marlatte, H. (2017). Neurobiology of schemas and schema-mediated memory.

Trends in Cognitive Sciences, 21(8), 618–631. doi:10.1016/j.tics.2017.04.013

Hennies, N., Lambon Ralph, M. A., Kempkes, M., Cousins, J. N., & Lewis, P. A. (2016).

Sleep spindle density predicts the effect of prior knowledge on memory consolidation.

*The Journal of Neuroscience, 36(*13), 3799–3810. doi:10.1523/JNEUROSCI.3162-15.2016

Iran-Nejad, A., & Winsler, A. (2000). Bartlett's schema theory and modern accounts of learning and remembering. *The Journal of Mind and Behavior*, 5-35.

Lewis, P. A., & Durrant, S. J. (2011). Overlapping memory replay during sleep builds cognitive schemata. *Trends in Cognitive Sciences, 15*(8), 343–351. doi:10.1016/j.tics.2011.06.004.

Muhmenthaler, M. C., & Meier, B. (2019). Task Switching Hurts Memory Encoding. *Experimental Psychology, 66,*(1), 58-67.

Piaget, J. (1952). *The origins of intelligence in children (Vol. 8),* International Universities Press.

Richter, F. R., & Yeung, N. (2012). Memory and cognitive control in task switching. *Psychological Science, 23,* 1256–1263.

Rogers, R. D., & Monsell, S. (1995) The costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.

Stickgold, R., Whidbee, D., Schirmer, B., Patel, V., & Hobson, J. A. (2000). Visual discrimination task improvement: A multi-step process occurring during sleep. *Journal of Cognitive Neuroscience, 12*(2), 246–54. doi:10.1162/089892900562075

Tononi, G., & Cirelli, C. (2003). Sleep and synaptic homeostasis: A hypothesis. *Brain Research Bulletin, 62,* 143-150. doi:10.1016/j.brainresbull.2003.09.004

Tse, D., Langston, R. F., Kakeyama, M., Bethus, I., Spooner, P. A., Wood, E. R. … Morris, R. (2007). Schemas and memory consolidation. *Science, 316,* 76–82.

van Kesteren, M. T. R., Beul, S. F., Takashima, A., Henson, R. N., Ruiter, D. J., & Fernández, G. (2013a). Differential roles for medial prefrontal and medial temporal cortices in schema-dependent encoding: From congruent to incongruent. *Neuropschologia, 51,* 2352-2359. doi:10.1016/j.neuropsychologie.2013.05.027

van Kesteren, M. T. R., Rijpkema, M., Ruiter, D. J., & Fernández, G. (2013b). Consolidation

differentially modulates schema effects on memory for items and associations. *PloS*

One, *8*(2), e56155.

Woodward, T. S., Meier, B., Tipper, C., & Graf, P. (2003). Bivalency is costly: Bivalent

stimuli elicit cautious responding. *Experimental Psychology, 50,* 233-238.