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Kontext, Inhibition und willentliche Unterdrückung im motorischen Gedächtnis

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Inhaltsverzeichnis

1. Danksagung

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2. Zusammenfassung

Diese Dissertationsschrift befasst sich mit der Erforschung des motorischen Gedächtnisses. Wir gehen der Frage nach, ob sich dort Analogien zu im deklarativen Gedächtnis bekannten kontextuellen und inhibitorischen Effekten finden lassen.

Der erste von drei *peer reviewed* Artikeln setzt sich mit der generellen Bedeutung von externen Kontextmerkmalen für einen motorischen Gedächtnisabruf auseinander. Wir veränderten zwei verschiedene Sätze motorischer Sequenzen entlang einer hohen Zahl entsprechender Merkmale. Signifikant unterschiedliche Erinnerungsleistungen wiesen auf eine Kontextabhängigkeit motorischer Inhalte hin. Die Erinnerungsleistung variierte entlang der seriellen Output-Position. Bei einem Kontextwechsel blieb die Erinnerungsleistung über den Abrufverlauf nahezu stabil, bei Kontextbeibehaltung fiel diese schnell signifikant ab.

Beide weiteren *peer reviewed* Artikel wenden sich dann der Inhibition motorischer Sequenzen zu. Im zweiten Artikel begutachten wir drei Sätze motorischer Sequenzen, die wir mit verschiedenen Händen ausführen ließen, auf ein selektives gerichtetes Vergessen. Die Vergessen-Gruppe zeigte dies nur, wenn für Satz Zwei und Drei dieselbe Hand benutzt wurde und somit ein hohes Interferenzpotenzial zwischen diesen Listen bestand. War dieses im Vergleich niedrig, indem beide Sätze mit verschiedenen Händen auszuführen waren, trat kein selektives gerichtetes Vergessen auf. Das deutet auf kognitive Inhibition als wirkursächlichen Prozess.

Im dritten Artikel schließlich untersuchen wir Effekte willentlicher kognitiver Unterdrückung sowohl des Gedächtnisabrufs als auch des Ausführens in einer motorischen Adaptation des TNT (*think/no-think*) – Paradigmas (Anderson & Green, 2001). Waren die Sequenzen in Experiment 1 anfänglich stärker trainiert worden, so zeigten willentlich unterdrückte (*no-think*) motorische Repräsentationen eine deutliche Verlangsamung in deren Zugänglichkeit und tendenziell auch in der Ausführung, - im Vergleich zu Basisraten-Sequenzen. Waren die Sequenzen in Experiment 2 dagegen nur moderat trainiert, wurden diese auch schlechter erinnert und deutlich verlangsamt ausgeführt. Willentliche kognitive Unterdrückung kann motorische Gedächtnisrepräsentation und deren Ausführung beeinflussen.

Unsere drei Artikel bestätigen motorische Analogien bekannter Kontext- und Inhibitionseffekte im deklarativen Gedächtnis. Wir führen ein selektives gerichtetes Vergessen motorischer Inhalte eindeutig auf Inhibition zurück und bestätigen darüber hinaus Effekte der willentlichen Unterdrückung motorischer Gedächtnisrepräsentation.

3. Einleitung

Vergleicht man die Anzahl der Forschungsergebnisse zum motorischen mit denen zum deklarativen Gedächtnis rein quantitativ, so könnte man den Eindruck gewinnen, es handle sich im ersteren Fall um ein großes Dunkelfeld. Diese Dissertation setzt sich im motorischen Gedächtnis mit zwei Einflussgrößen auseinander, die im deklarativen Gedächtnis bedeutsame Faktoren prominenter Erklärungsmodelle zum gerichteten Vergessen sind (für einen Überblick siehe MacLeod, 1998), Kontext und Inhibition. Der inhibitorische Erklärungsansatz geht von einem per Inhibition aufgelösten Interferenzpotenzial aus, was zu den Kosten führt (etwa Geiselman et al., 1983). Der Kontextwechselansatz (Sahakyan & Kelley, 2002) führt die Kosten dagegen auf eine Diskrepanz zwischen dem Encodier- und Abrufkontext zurück. In drei *peer reviewed* Artikeln gehen wir sowohl der Frage motorischer Analogien dieser zwei im deklarativen Gedächtnis bekannten Wirkfaktoren als auch deren Bedeutung für das selektive gerichtete Vergessen motorischer Inhalte nach, schließlich wenden wir uns der willentlichen kognitiven Unterdrückung motorischer Inhalte zu.

Im ersten der drei Artikel dieser Dissertation befassen wir uns mit der Frage, ob sich eine Kontextabhängigkeit intentional gelernter motorischer Gedächtnisinhalte generell einstellt. Zwischen Encodierung und Abruf zweier Sätze motorischer Inhalte veränderten wir eine Vielzahl kontextueller Eigenschaften in der Umweltdimension und konnten eine Kontextabhängigkeit der Erinnerung motorischer Inhalte nachweisen. Die Ergebnisse entsprachen den diesbezüglichen Vorhersagen der Theorie der „Zwei Gesichter des Gedächtnisabrufs“ (etwa Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010). Die Gedächtnisprozesse der sich ausbreitenden Aktivierung oder der Inhibition (Roediger & Neely, 1982) scheinen also auch den motorischen Gedächtnisabrufverlauf so zu moderieren, wie es für den deklarativen bekannt ist.

Obwohl wir eine Kontextabhängigkeit der Erinnerungsleistung für motorische Inhalte belegen konnten, verhielten sich diese Inhalte in einem Ansatz des selektiven gerichteten Vergessens für drei kleine Sätze motorischer Repräsentationen in Artikel 2 nicht so, wie es der Kontextwechselansatz (Sahakyan & Kelley, 2002) erwartet. Variierten wir das Interferenzpotenzial zwischen Satz Zwei und Drei, indem wir diese mit verschiedenen oder der gleichen Hand ausführen ließen, stellte sich selektives gerichtetes Vergessen für den mittleren Satz nur ein, wenn wir diesen mit der gleichen Hand wie den nachfolgend zu encodierenden ausführen ließen. Dies legt die Gültigkeit der Interferenzabhängigkeit der Inhibition (Anderson, 2003) auch für motorische Repräsentationen nahe und weist eindeutig auf kognitive Inhibition als Ursache des selektiven gerichteten motorischen Vergessens in unserem Versuchsaufbau hin. Darüber hinaus kann der Kontextwechselansatz (Sahakyan & Kelley, 2002) unser Ergebnismuster für motorische Repräsentationen nicht erklären. Implementierten wir also Aufgabenanforderungen, die einen Kontexteffekt begünstigten (Artikel 1), so trat dieser auch auf. Wenn wir stattdessen kognitive Inhibition ermöglichten (Artikel 2), so kam es zu einer Inhibition motorischer Gedächtnisrepräsentationen. Die Salienz einer Wirkgröße für die Aufgabe könnte entscheidend sein. Anderson und Hulbert (2021) legen in ihrem Modell des aktiven Vergessens darüber hinaus dar, dass eine kognitive Inhibition des mentalen Kontexts ebenso denkbar wäre. Das Modell postuliert einen Kontextzwischenspeicher, dessen Inhalte per Inhibition entladen werden können. Ein Zusammenwirken beider Faktoren auf ausschließlich inhibitorischem Wirkniveau kann gegeben sein. Kontext und Inhibition müssen nicht als nur konkurierende Erklärungen für Effekte des Gedächtnisabrufs begriffen werden, ein Zusammenwirken beider Faktoren zur erfolreichen Gedächtnisorganisation ist ebenso plausibel.

Im dritten Artikel fanden wir erneut ein motorisches Pendant zur kognitiven Inhibition, diesmal in Form einer willentlich initiierten Unterdrückung motorischer Inhalte. Die willentliche Unterdrückung motorischer Sequenzen, sowohl in Ausführung als auch im Abruf, wies in einer motorischen Adaptation des TNT (*think/no-think*) – Paradigmas (Anderson & Green, 2001) eine deutliche Verlangsamung der Zugänglichkeit und eine Tendenz zur verlangsamten Ausführung dieser Inhalte auf, waren diese anfänglich gut trainiert. Geschah dies nur moderat, stellte sich auch ein Effekt in der Erinnerungsgenauigkeit und in der Ausführungsgeschwindigkeit dieser willentlich unterdrückten motorischen Inhalte ein, gegenüber Basisraten-Inhalten. Wir wiesen unterdrückungsinduziertes Vergessen motorischer Inhalte nach.

Zusammengenommen sprechen die Ergebnisse unserer drei Artikel für motorische Analogien aus dem deklarativen Gedächtnis bekannter Effekte von Kontext und Inhibition. Wir fanden eine Kontextabhängigkeit der Erinnerung an motorische Repräsentationen, konnten ein selektives gerichtetes Vergessen motorischer Inhalte aber eindeutig auf kognitive Inhibition zurückführen, der Kontextwechselansatz kann unser Ergebnismuster nicht erklären. Auch Effekte einer willentlichen Unterdrückung motorischer Repräsentationen ließen sich bestätigen. Die gefundenen motorischen Analogien zur Inhibition deklarativer Inhalte deuten auf ein unabhängig vom Repräsentationssystem wirkendes allgemeines Prinzip der Inhibition hin, das modalitätsübergreifend direkt an der Repräsentation selbst wirkt und auch willentlich rekrutiert werden kann.

3.1. Einleitung Artikel 1

Der Kontext unserer unmittelbaren Umgebung hat stets einen Einfluss auf unsere Erinnerung. Dieser Effekt ist für das deklarative Gedächtnis wohlbekannt. Für diese Inhalte ist vielfach gezeigt worden, dass ein Wechsel im Kontext dem Abruf abträglich, eine Beibehaltung des Encodierkontexts dagegen hilfreich ist (etwa Godden & Baddeley, 1975; Smith et al., 1978). Im Hinblick auf die Encodierbedingungen unterscheiden sich deklarative Repräsentationen häufig zu den motorischen, da bei Letzteren meist keine Behaltensabsicht besteht. Untersuchungen zur Kontextabhängigkeit des motorischen Gedächtnisses setzen sich überwiegend mit der inzidentellen Aneignung von motorischen Fertigkeiten auseinander. Teilnehmende haben eine motorische Aufgabe unter verschiedenen Kontextbedingungen mehrmals bis sehr oft auszuführen, ohne dass eine explizite Lernabsicht zum Behalten dieser motorischen Fertigkeit(en) vorliegt (etwa Ruitenberg et al., 2012). Deren Speicherung ist mehr oder minder ein beiläufiges Nebenprodukt oftmaliger Ausführung, aber nicht explizit gefordert.

Tempel und Frings (2016) fanden in ihrer Untersuchung zur Listen-Methode gerichtetes Vergessen (LMDF, *list method directed forgetting*, Bjork, 1970; für einen Überblick siehe MacLeod, 1998) motorischer Inhalte eine mögliche Kontextabhängigkeit des motorischen Gedächtnisses. Teilnehmende hatten in der Lernphase zwei aufeinanderfolgende Sätze zu je fünf motorischen Sequenzen mehrmals auszuführen und sich dabei willentlich einzuprägen. Der Fokus lag hier also auf dem intentionalen Erinnern von Bewegungen. Jede motorische Sequenz bestand aus vier aufeinanderfolgenden Fingerbewegungen dreier Finger der rechten Hand, die über Tastendrucke nachzutippen waren. Nun erhielt die Hälfte der Teilnehmenden nach der ersten Liste (L1) die Instruktion, diese zu vergessen, diese Liste hätte nur den Zweck gehabt, die Teilnehmenden mit der Prozedur vertraut zu machen, quasi eine Aufwärmübung (Vergessen-Gruppe). Die andere Hälfte der Teilnehmenden erhielt nach der ersten Liste dagegen die Anweisung diese und die nächste Liste (L2) zu behalten (Erinnern-Gruppe). Nach einer Ablenkungsaufgabe fand für beide Gruppen ein abschließender freier Abruf statt, in der alle Sequenzen beider Sätze einzugeben waren. Zuerst sollten ungeachtet vorheriger Gruppen-Instruktionen alle Elemente von L1 erinnert werden, danach alle L2-Sequenzen (zur Kontrolle von Output Interferenz, Roediger, 1974; Smith, 1971; siehe hierzu Seite 8).

Das typische Ergebnis im Paradigma des gerichteten Vergessens besteht aus einem Nutzen- und einem Kosteneffekt. Die Vergessen-Gruppe erinnert L2 üblicherweise besser als die Behalten-Gruppe (Nutzeneffekt). Zusätzlich stellt sich oft ein Kosteneffekt ein, die Vergessen-Gruppe erinnert signifikant weniger L1-Elemente. Kosten zeigten sich in den zwei

Experimenten von Tempel und Frings (2016) allerdings nur in Experiment 2, der L2-Nutzen trat hingegen in beiden Experimenten auf. Nutzen ohne Kosten wurden in der Listenmethode des gerichteten Vergessens bereits beobachtet (Benjamin, 2006; Paststötter & Bäuml, 2010), was einfaktorielle Erklärungsmodelle (siehe hierzu Kapitel 3.2.) zur Entstehung von Kosten *und* Nutzen infrage gestellt hatte. Neuere Erklärungsansätze nehmen zwei verschiedene voneinander unabhängige Prozesse an. Die ROE-Theorie (*reset of encoding*) etwa postuliert, dass das Vergessen-Signal den Encodierungsprozess zurücksetzt. Ausgehend von der Beobachtung, dass die Encodierungseffizienz mit zunehmender Anzahl der zu encodierenden Elemente typischerweise sinkt, wird das nachfolgende Encodieren der L2-Elemente deshalb wieder so effizient wie bei L1, was für den L2-Nutzen verantwortlich ist (Pastötter & Bäuml, 2010; Pastötter et al., 2017). Sahakyan und Delaney (2003) erklären den L2-Nutzen mit der häufigeren Anwendung der Strategie einer tieferen Verarbeitung in der Vergessen-Gruppe. Die L1-Kosten erklären zweifaktorielle Theorien wie die einfaktoriellen. Eine Reduktion der proaktiven Interferenz (Underwood, 1957) von L1 auf L2 entweder per Inhibition (Geiselman et al., 1983) oder per Kontextwechsel (Sahakyan & Kelley, 2002).

Hinsichtlich unserer kontextuellen Fokussierung ist hier von Interesse, welche Veränderungen im Versuchsaufbau von Experiment 1 auf 2 vorgenommen wurden. Experiment 2 unterschied sich von Experiment 1 durch eine dreiminütige Pause zwischen L1 und L2 sowie einen Wechsel der Reaktionstasten von L1 auf L2. Diese beiden Wechsel externer Kontextmerkmale könnten den abschließenden freien Abruf beider motorischer Sätze beeinflusst haben. Die externen Wechsel hätten auch einen internen Wechsel verursacht haben können. Das Auftreten des Kosteneffekts nur nach diesen Wechseln stellte den Ansatzpunkt für die Planung unseres Versuchsdesigns im Experiment des ersten veröffentlichten Artikels dar.

Analog zu Tempel und Frings (2016) entwarfen wir zwei Sätze (L1 und L2), diesmal zu je acht motorischen Sequenzen, wobei jede Sequenz aus drei aufeinanderfolgenden Fingerbewegungen der rechten Hand bestand. Wright und Shea (1991) differenzierten Stimuli der Umweltdimension in intentionale und inzidentelle. Intentionale fassten sie als „essenziell für eine geübte Ausführung“ (Seite 361) auf. In unserem Fall zweier Sätze von Fingersequenzen stellen beispielsweise die Animation der Fingersequenzen auf dem Bildschirm oder die verwendeten Reaktionstasten je einen intentionalen Stimulus dar. Inzidentelle hingegen definierten sie als solche, „die das Potenzial haben, mit spezifischen Aufgaben aufgrund ihrer selektiven Präsenz in der Lernumgebung assoziiert zu werden“ (Seite 361), wie etwa die Gestaltung des Arbeitsplatzes oder der Benutzeroberfläche am Rechner. Zwischen Encodierung und Abruf veränderten wir nach Wright und Shea (1991) eine Vielzahl kontextueller

Eigenschaften in der Umweltdimension.

Unsere Teilnehmenden durchliefen zwei intentionale Lernphasen zweier verschiedener Sätze, deren essenziellen und inzidentellen Stimuli aufmerksamkeitsinduzierend auffällig unterschiedlich gehalten waren. Die Instruktionen für jede Lernphase forderten allerdings nur zur Aneignung möglichst aller Sequenzen auf, diese Unterscheidung wurde nicht erwähnt. Nach der Aneignung von L1 verliessen die Teilnehmenden den Raum für zehn Minuten, ebenso fand der Test für beide Sätze erst zehn Minuten nach der Lernphase für L2 statt, die an einem anderen Arbeitsplatz als für L1 stattfand, und nach der die Teilnehmenden den Raum erneut zu verlassen hatten. Die Pausen ohne eine Aufgabe sollten einen internen Kontextwechsel fördern.

Der Test selbst fand nun in vier verschiedenen Bedingungen statt. In der ersten Hauptbedingung, der "Wechsel"-Gruppe, wechselten wir den Kontext komplett zurück zu L1, inzidentelle wie intentionale Stimuli entsprachen L1. Die zweite Variante, die "Kein Wechsel"-Gruppe, führte den Test dagegen am Arbeitsplatz von L2 durch, eben mit den inzidentellen und intentionalen Stimuli von L2, der Kontext der letzten Lernphase wurde beibehalten. Zwei weitere Bedingungen stellten den inzidentellen Testkontext analog auf L1 oder L2 um, die intentionalen visuellen Stimuli waren hier allerdings in einem neuen, wenn man so will "neutralen" Stil gehalten, der weder zu L1 noch zu L2 passte. Die Reaktionstasten dagegen waren passend zu L1 oder L2. In diesen beiden "neutralen" Gruppen wurde der Kontext also nur teilweise wiederhergestellt oder beibehalten.

Die Theorie der „Zwei Gesichter des Gedächtnisabrufs“ (etwa Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010) ist eine Zwei-Faktoren-Erklärung für verschiedene Verläufe von Abrufleistungen, diese auf die An- oder Abwesenheit eines Kontextwechsels zwischen der Encodier- und der Abrufphase zurückführend. Erfolgt ein Kontextwechsel, gerät der Abruf entlang der Versuche zu einem selbstpropagierenden Prozess. Aufgrund einer angenommenen Deaktivierung des Encodierkontexts (durch internen oder externen Wechsel) stellen die ersten erfolgreichen Abrufversuche dieses zuvor deaktivierten Kontextmaterials dann dessen Zugang für nachfolgende Abrufversuche wieder her. Der Abrufzugang weiterer Elemente aus diesem Kontext wird über die weiteren Abrufversuche erleichtert, der Abruf gerät zu einem selbstpropagierenden Prozess. Findet dagegen kein Kontextwechsel zwischen Encodier- und Abrufphase statt, verschlechtert sich die Abrufleistung nach den ersten erinnerten Inhalten aus diesem Kontext zusehends, da dieser erfolgreiche Abruf den Abruf von Elementen aus dem anderen Kontext nachfolgend blockiert oder inhibiert. Der Abruf gerät zu einem selbstlimitierenden Prozess (Bäuml & Schlichting, 2014). Im Paradigma der Output-Interferenz (Roediger, 1974; Smith, 1971) etwa zeigt sich als typisches Ergebnismuster, dass der erfolgreiche vorangehende Abruf der einen Elemente den nachfolgenden Abruf der anderen Elemente beeinträchtigt. Was vorangehend erinnert wird, beeinflusst, was nachfolgend erinnert wird. Ähnlich reduziert die Präsentation einiger Elemente als Hinweisreiz zum Abruf den nachfolgenden Abruf anderer Elemente (*part-set cueing*, etwa Roediger, 1973; Slamecka, 1968). Hinsichtlich dieser zwei Gesichter im Abruf entscheidet also der nicht erfolgende Wechsel im Kontext über einen inhibierenden Verlauf, der erfolgende über einen ausbreitend aktivierenden. Analog sahen Roediger und Neely (1982) Inhibition oder sich ausbreitende Aktivierung als konkurrierende Erklärungen für die Effekte des Gedächtnisabrufs (Bäuml & Samenieh, 2010).

Teilnehmende in unserem Experiment hatten im Abruf die Instruktion erhalten möglichst alle Sequenzen beider Sätze zu erinnern oder zu raten. Wir unterschieden unsere resultierenden 16 Abrufergebnisse im Hinblick auf deren Verlauf in zwei Gruppen. Die ersten acht erinnerten Sequenzen (T1) und die zweiten acht erinnerten Sequenzen (T2). Für unsere vier Bedingungen erwarteten wir gemäß der Theorie der „Zwei Gesichter des Gedächtnisabrufs“ einen selbstlimitierenden Abrufverlauf für die “Kein-Wechsel”-Gruppe. Der Abruf der “neutrale Kein-Wechsel”-Gruppe sollte ebenso selbstlimitierend verlaufen. Deren neutralen visuellen Stimuli sollten für einen Kontextwechsel nicht ausreichen. Die “Wechsel-Gruppe” müsste einen selbstpropagierenden Abrufverlauf haben. Die neutralen Stimuli in der “neutrale Wechsel”-Gruppe dagegen könnten einen Kontextwechsel zurück zu L1 verhindern, so bliebe der Kontext von L2 aktiv und der Abruf sollte in diesem Fall ebenso selbstlimitierend verlaufen. Im Ergebnisüberblick erwarteten wir also lediglich die “Wechsel”-Gruppe als einen selbstpropagierenden Verlauf aufweisend.

3.2. Einleitung Artikel 2

Der zweite Artikel dieser Dissertation setzt sich mit der Inhibition motorischer Sequenzen im Paradigma des selektiven gerichteten Vergessens auseinander. Anderson (2003) argumentiert zur Inhibition aus einer Makroperspektive. Hier ist der Gedächtnisabruf nur noch eine von vielen Gedächtnisfunktionen, - die Kontrollprozesse ausüben. Ob willentlich oder nicht sei dahingestellt. Vergessen im Rahmen seiner Interferenztheorie resultiert nicht einfach nur aus der Konkurrenz interferierender Inhalte um Zugang zum Bewusstsein (Abruf-Interferenz, McGeoch, 1942) oder deren Encodierung per se (retroaktive Interferenz, nachher Gelerntes überlagert vorher Gelerntes, Müller & Pilzecker, 1900; oder proaktive Interferenz, die Überlagerung einer neuen Assoziation durch vorher Gelernte, Underwood, 1957). Seiner Interferenztheorie nach ist es der spezifische Kontrollprozess der kognitiven Inhibition, der diese Interferenz überwindend zur Hemmung irrelevanter Inhalte (etwa hinsichtlich momentaner Primärziele) führt. Anderson (2003) versteht Inhibition also als eine den Aktivierungsgrad potenziell interferierender Gedächtnisreaktionen reduzierende Funktion (*response override*), aber "Interferenz ist nicht Inhibition" (MacLeod, 2003, Seite 49). Inhibitorische kognitive Prozesse, die der Kontrolle des Gedächtnisabrufs dienen, führen die Hemmung interferierender konkurrierender Inhalte herbei. Sie beseitigen die Interferenz zwischen diesen Inhalten – per kognitiver Inhibition des aktivierten Inhalts selbst.

Das Paradigma des selektiven gerichteten Vergessens knüpft an die Listenmethode des gerichteten Vergessens an. In LMDF (Bjork, 1970) wird relativ unspezifisch der Frage nach unserer Fähigkeit zum erfolgreichen Vergessen obsoleter Information zugunsten der Zugänglichkeit aktuell relevanter Gedächtnisinhalte nachgegangen. Selektives gerichtetes Vergessen beschreibt die empirische Beobachtung, dass aus beispielsweise drei zuvor gelernten Listen genau nur die zweite Liste (L2) - wie nach dem Lernen der Liste instruiert - vergessen wird, die erste (L1) und dritte Liste (L3) aber behalten wurde. Dieses Paradigma kommt alltäglichen Gedächtnisprozessen näher, da hier meist nicht komplette, sondern nur spezifische Inhalte (nur L2 aus drei Listen) aktualisiert, vergessen werden sollen. Sahakyan (2004) verwendete diese Drei-Listen-Methode als Erste, um der Frage der Selektivität im gerichteten Vergessen nachzugehen. Ihre Ergebnisse zeigten listenweises gerichtetes Vergessen, aber das Vergessen von L2 weitete sich auf L1 aus. Sahakyan (2004) fand also keine Selektivität im gerichteten Vergessen. Kliegl et al. (2013) hingegen fanden selektives gerichtetes Vergessen in einer Drei-Listen-Aufgabe. Sahakyan (2004) hatte relativ lange Listen zu je einem Dutzend Elemente verwendet, Kliegl et al. (2013) dagegen relativ kurze Listen.

In LMDF finden sich miteinander konkurrierende Erklärungsmodelle. Bjork (1970) geht in seinem Ein-Faktor-Modell von einem selektiven Lernabruf der zu erinnernden Materialien aus, was sowohl zum Kosten- als auch zum Nutzeneffekt führt. Sahakyan und Kelley (2002) gehen in ihrem Kontextwechsel-Ansatz dagegen von einem durch die listenbezogene Vergessensinstruktion ausgelösten mentalen Kontextwechsel aus. Dieser interne Kontextwechsel soll nun die Zugänglichkeit allen vor dem Vergessen-Signal gelernten Materials mindern. Der Abruf der „Vergessen-Liste" im Test leidet also unter der Divergenz zwischen dem Encodier- und dem Abrufkontext. Geiselman et al. (1983) als Protagonisten des dritten prominenten einfaktoriellen Erklärungsansatzes führen die Kosten für die „Vergessen-Liste" in ihrer Abruf-Inhibitionstheorie auf aktive inhibitorische Kontrollprozesse zurück, die

die Zugänglichkeit derer Elemente behindern. Mit dem Begriff Abruf-Inhibition ist gemeint, dass der inhibierte oder unterdrückte Inhalt zwar weiterhin im Gedächtnis vorhanden, der Abruf-Zugang aber vermindert oder beeinträchtigt ist (Bjork et al., 2006, S. 135).

Nur der Kontextwechsel-Ansatz (Sahakyan & Kelley, 2002) erwartet für die eingangs beschriebene Drei-Listen Variante, in der nur L2 vergessen werden soll, keine Selektivität im gerichteten Vergessen. Alle vor dem Vergessen-Signal gelernten Elemente sollten von dem dadurch angenommen erfolgten Kontextwechsel betroffen sein. Die beiden anderen Erklärungsmodelle können ein potenzielles selektives Vergessen von L2-Elementen erklären. Somit bleibt aber auch unklar, welches theoretische Modell zutreffend ist, sollte es zum Vergessen von L2 kommen, - und L1 dabei behalten werden. Um einen drei Listen umfassenden Versuchsaufbau zu implementieren, der Ergebnismuster eindeutig zwischen diesen drei Erklärungsansätzen zu differenzieren vermag, verwendeten wir einen Ansatz dreier kurzer Sätze motorischer Sequenzen in zwei Varianten. In beiden Varianten war L2 natürlich entweder zu behalten oder zu vergessen.

Die zweite und wesentlichere Bedingungsdifferenzierung im Versuchsaufbau war ein Interferenzpotenzial zwischen L2 und L3, dass wir generierten, indem wir L3 entweder mit derselben oder mit der anderen Hand wie L2 ausführen ließen. Die Forschung zum abrufinduzierten Vergessen (der Abrufprozess an sich kann Vergessen verursachen, Anderson et al., 1994) motorischer Inhalte hat gezeigt, dass die Hände als distinkte Kategorien zur Gedächtnisorganisation angesehen werden können (Tempel et al., 2016; Tempel & Frings, 2014a, 2014b, 2015, 2017). In unserem Versuch wurde L1 immer mit der linken Hand ausgeführt und gelernt, L2 immer mit der rechten. Da nun für L3 entweder die linke oder die rechte Hand verwendet wurde, konnte das Ergebnis des Versuchs eindeutig auf eine Theorie zurückgeführt werden, sollte es überhaupt zu einem selektiven gerichteten Vergessen motorischer Sequenzen kommen.

Würden sowohl der Abruf von L1 als auch der von L2 unter der Vergessensinstruktion leiden, so träfe der Kontextwechsel-Ansatz (Sahakyan & Kelley, 2002) zu. Das Vergessen-Signal ist der Zeitpunkt des Wechsels im Kontext und alle Inhalte vor diesem sollten im finalen Abruf beeinträchtigt sein. Wird dagegen L2 selektiv vergessen, egal ob L3 mit der linken oder der rechten Hand auszuführen und zu lernen war, so trifft die Erklärung des selektiven Lernabrufs (Bjork, 1970) zu. Kommt es dagegen nur in der Bedingung zu einem selektiven Vergessen von L2, in der L3 auch mit der rechten Hand zu bearbeiten war, so trifft die Abruf-Inhibitionstheorie (Geiselman et al., 1983) zu. Nur wenn der Effektor zwischen L2 und L3 wiederholt wird, kann es zu einer Interferenz zwischen diesen beiden Sätzen kommen. Diese Konkurrenz beider Sätze um Zugang zum Bewusstsein wird dann zum Ziel des adaptiven Inhibitionsmechanismus, in dessem Wirken die Interferenz zwischen L2 und L3 per Inhibition der L2-Elemente aufgelöst wird. Sollte es in unserem Versuchsaufbau zu einem erstmaligen Nachweis selektiven gerichteten Vergessens im motorischen Gedächtnis kommen, so erwarteten wir dies für die Bedingung, in der für L2 und L3 dieselbe Hand Verwendung fand. Wir favorisierten die Abruf-Inhibitionstheorie (Geiselman et al., 1983).

3.3. Einleitung Artikel 3

Auch im letzten Artikel dieser Dissertation geht es um die Inhibition im motorischen Gedächtnis. Hier widmen wir uns der Wirkung von willentlicher Unterdrückung sowohl des Gedächtnisabrufs als auch des Ausführens motorischer Sequenzen auf einen nachfolgenden Abruf. Freud (1915) schlug den Prozess der Verdrängung vor, der es uns ermöglicht unerwünschte Gedanken in das Unbewusste zu verschieben. Willentliche Unterdrückung kann als die bewusste Form der Verdrängung nach Freud (1915) verstanden werden (Anderson & Green, 2001). Zur Vermeidung unerwünschter Gedanken meidet man im Allgemeinen die diese Erinnerungen auslösenden Reize. Der Erinnerung dann aber in der Gegenwart eines auslösenden Reizes nicht gewahr zu werden, bedeutet Kontrolle über den Gedächtnisabruf auszuüben. Den Abruf einer unerwünschten Erinnerung zu verhindern geschieht per Abrufunterdrückung. Die Erinnerungen auslösenden Reize fördern das Behalten, wenn man dieser Erinnerung zugeneigt ist, diese zulässt. Wenn man aber dazu motiviert ist eine Erinnerung aus dem Bewusstsein herauszuhalten, kann man den Abruf dieser Erinnerung bewusst aufhalten. Diese Abrufunterdrückung wird oft im Rahmen des TNT (*think/no-think*) – Paradigmas untersucht, das eben Situationen imitiert, in denen wir unerwünschte Erinnerungen vermeiden (Anderson & Hanselmayr, 2014).

Anderson und Green (2001) entwarfen das TNT (*think/no-think*) - Paradigma, um die Konsequenzen willentlicher Unterdrückung deklarativer Gedächtnisrepräsentationen zu erforschen. Teilnehmende lernten zuerst 40 Zielwörter mit einem Hinweiswort zu assoziieren, etwa “Flagge – Schwert”, sodass sie auf das Hinweiswort laut mit dem Zielwort antworten konnten. Anschließend begann die TNT-Phase, in der in einer variablen Durchgangszahl entweder das Erinnern und Aussprechen (*think* Übung) oder die verbalmotorische und kognitive Unterdrückung (*no-think* Übung) des Zielworts auf das auslösende Hinweiswort hin trainiert wurde. In der *no-think* Übung sollte das Zielwort also nicht nur nicht ausgesprochen, sondern bestmöglich sogar jeder Gedanke an dieses Wort vermieden werden. Die (in variabler Anzahl) mehrfach wiederholte willentliche Abruf- und verbalmotorische Unterdrückung der Zielwörter hatte einen negativen Einfluss auf deren spätere Erinnerungsgenauigkeit. *No-think* Wörter wurden im Vergleich zu Basisraten-Wörtern (die in der Zwischenzeit nicht vorkamen) schlechter erinnert. Wir passten dieses Paradigma für motorische Gedächtnisinhalte in zwei Experimenten an, um Effekte willentlicher Unterdrückung dieser Inhalte zu untersuchen. Anstelle von Wortpaar-Assoziationen verwendeten wir Buchstabe-Sequenz-Assoziationen (Siehe **Abbildung 1** untere Hälfte).

Nachdem Teilnehmende an unserer motorischen Adaptation die Lernphase mit einem bestimmten Kriteriumswert (75 % korrekt erinnert von 12 Sequenzen für Experiment 1, 50 % korrekt erinnert von 16 Sequenzen für Experiment 2) oder per Durchgangslimit abgeschlossen hatten, begann die TNT-Phase. Hierin wurden nur die Hand und der entsprechende Konsonant randomisiert präsentiert. Für *think*-Durchgänge in Grün, für *no-think*-Durchgänge in Rot. Grüne

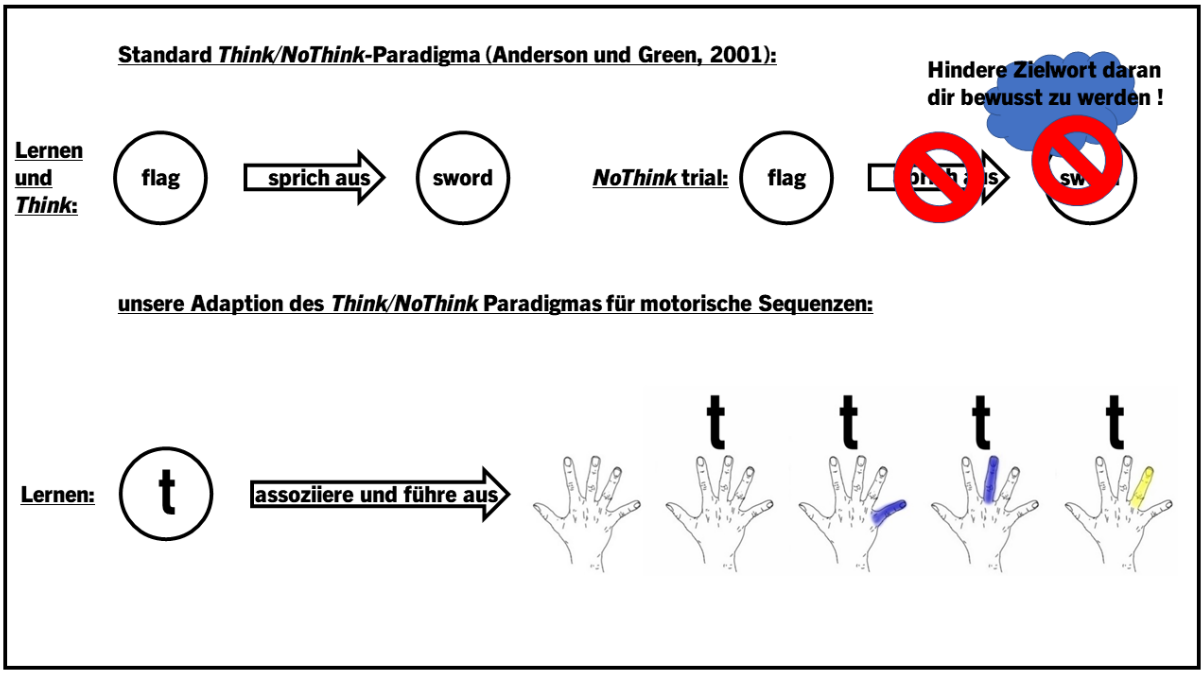

Abbildung 1. In der oberen Zeile ein Beispiel für einen *think* (links) und einen *no-think* Durchgang (rechts) aus Anderson und Green (2001). In der unteren Zeile ein Beispiel aus der Lernphase unserer Adaptation des Paradigmas für motorische Sequenzen. Erst wird die Hand gezeigt, dann der Buchstabe, dann leuchteten die drei Finger der zum Buchstaben zu assoziierenden Sequenz nacheinander auf und Teilnehmende hatten diese danach auszuführen und zu behalten.

Hand und Konsonant indizierten, die Sequenz zu erinnern und auszuführen. Rote Hand und Konsonant waren mit der Instruktion verbunden die Sequenz auf keinen Fall einzutippen und bestmöglich jeden Gedanken daran zu hindern, den Teilnehmenden bewusst zu werden.

Wie Anderson und Green (2001) erwarteten wir, dass die willentliche motorische und kognitive Unterdrückung der *no-think* Sequenzen für diese zu einem Nachteil in der Erinnerungsgenauigkeit in einem abschließenden Test führen würde.

4. Originalmanuskripte

Kapitel 4 enthält alle Originalmanuskripte von drei Artikeln (4.1., 4.2., 4.3.), die alle drei bereits *peer-reviewed* akzeptiert und in *journals* veröffentlicht wurden.

4.1. Artikel 1: Context-Dependent Memory of Motor Sequences

Der nachfolgende Artikel ist veröffentlicht worden als:

Schmidt, M., Frings, C., & Tempel, T. (2021). Context-Dependent Memory of Motor Sequences. Journal of Cognition, 3(1): X, pp. 1–12. DOI: https://doi.org/10.5334/joc.152

Context-Dependent Memory of Motor Sequences

Schmidt, M., Frings, C., Tempel, T.

ABSTRACT

To examine influences of context changes between encoding and retrieval of motor sequences, we varied a number of encoding and retrieval features in a two lists approach. Participants consecutively learned two sets of three-finger movements at two different computer working places, all enacted with fingers of the right hand. We varied keyboard and display orientation, stimuli, background color, response keys, position of the hand, and the used PC between the two set. A final free recall test comprised either the same context features as present during study of the first item set or the ones present during study of the second item set or novel test context features. Results showed significant differences in overall recall performance between test conditions, indicating that context features of study episodes guided retrieval of motor sequences. In addition, the number of recalled items varied as a function of output position. Test context elements comprising context features of the first item set study episode were associated with initially lower but subsequently nearby stable recall performance, whereas test features comprising context elements of the second item set study episode were associated with initially higher and subsequently decreasing recall performance. This implies that a context reinstatement for list-1 items during the test phase does not immediately enhance accessibility of those items. However, access is subsequently facilitated over the course of retrieval attempts.

KEYWORDS:

context change; intentional context stimuli; incidental context stimuli; context-dependent learning; context-dependent retrieval

The context-dependency of memories typically is a subtle phenomenon. Imagine the everyday situation where you stand in the cashiers waiting line of your local supermarket. You can't remember where you parked your car in the supermarket parking lot while trying to think of it inside. But standing on this parking lot after leaving the market you immediately recall the position of your car. This (environmental) context-dependent memory phenomenon received empirical evidence in Godden and Baddeley's (1975) classical study, wherein they created two remarkably different natural environmental situations – on land and under water. Memory for word lists learned on land was best if the lists were recalled on land, word lists learned under water were best recalled under water. Lists learned on land getting recalled under water or lists learned under water getting recalled on land produced reliably worse recall. So, memory performance (for word lists in that case) depended on the contextual match between the retrieval and the encoding situation, i.e. recall was better if the environment of original learning had been reinstated.

Context has a fundamental impact on memory, effects of environmental context changes on subsequent recall were found for room changes (Smith, Glenberg, & Bjork, 1978), for background music (Smith, 1985), for odors (Pointer & Bond, 1998), and the background color of a monitor (Isarida & Isarida, 2007), to name just a few examples. Context change effects also expand to posture (Rand & Wapner, 1967). A pose as a contextual (background) cue could reflect a temporal-spatial or a social-emotional context as well as an internal state driven element just present in your mind. So beyond external (physical) attributes, there may be an internal or mental contextual cue. Bower (1981) for example examined mood-state-dependent memory in recall of word lists. Sahakyan & Smith (2014) referred to mental context as: "our constantly changing blend of thoughts that evolves in response to encoding and retrieval of other events" (p. 86). We here always will refer to environmental (external) context, whenever we speak of context, or name explicitly which context we speak of.

Evidence for a context-dependency of motor memory is much more limited. Ruitenberg, De Kleine, Van der Lubbe, Verwey, & Abrahamse (2012) examined context-dependent learning in the discrete sequence production task. In this task, participants typically face two sequences of two to seven stimuli in a fixed order and respond by means of spatially compatible key presses. Ruitenberg et al. (2012) presented two differently colored stimuli simultaneously, one relevant and one irrelevant. Performance was impaired when the irrelevant information was changed in the test phase, but not when it was removed, showing that sequence learning in the discrete sequence production task is context-dependent and that the context dependency was modulated by the amount of practice; the context effects diminished as practice increased.

Wright and Shea (1991) used a different approach to examine contextual dependencies during motor skill acquisition. They proposed a distinction for the environmental dimension into intentional and incidental stimuli. Whereas intentional stimuli “were defined as essential for achieving skilled performance”, incidental stimuli “were defined as those that have the potential to become associated with specific tasks due to their selective presence in the learning environment” (p. 361). In their Experiment 1, they manipulated the proportion of intentional and incidental stimuli between learning and test. The same intentional and same incidental stimuli (as in the learning phase) were given at test in one condition (context reinstatement), the same intentional but switched incidental stimuli in another condition, and finally no intentional but same incidental stimuli in a third condition. Participants were told to make use of the intentional stimuli for planning and enactment of the keypress sequences, but the incidental stimuli were not mentioned at all. Their performances showed less errors in the reinstatement condition than in the same intentional but switched incidental stimuli condition. Both conditions involving a change of stimuli at test showed reduced performance as compared to context reinstatement. Memory for motor skill performances showed a reliable context-dependency.

Tempel and Frings (2016) examined directed forgetting (the intentional effort to forget previously encoded information) in motor memory and found evidence for a context-dependency of motor memory. Two lists of sequential finger movements served as item material. Each sequential finger movement consisted of consecutive key presses from four fingers of the right hand. A cost effect of directed forgetting (i.e. the *forget*-cued list is recalled worse than the *remember*-cued list) for List one (L1) only emerged in Experiment 2, which involved a three-minute break between L1 and List two (L2) along with different response keys for L2 as for L1. Test phase response keys were those of L2. The motor sequences recall in this study might have depended on the changes in external (context) features, such as different response keys and a three-minute break between L1 and L2, that also may have facilitated a change in the internal context as a consequence of the forget instruction for L1.

THE PRESENT STUDY

Previous studies on the context dependency of motor memory focused on incidental motor skill acquisition. Wright and Shea’s (1991) distinction between intentional and incidental stimuli only referred to directing attention to features that guided performance of a motor task (intentional) versus background features (incidental). However, learning motor sequences is not always a mere by-product of repeatedly performing a certain task. In many situations, there is an intention to learn and retain certain motor sequences, for example, when practicing how to play a piece of music on an instrument. Here, we examined effects of switching intentional and incidental stimuli, as defined by Wright and Shea (1991), on an intentional learning setting of motor sequences.

With respect to the results of Tempel and Frings' (2016) directed forgetting study, that might reflect evidence for a context-dependency of motor memory, we used a similar design in this study, this time focusing only on contextual changes between two lists – and at test. In the present study, participants learned two lists of sequential finger movements consecutively, both followed by a ten-minute break. We designed two different sets of eight sequences, with each sequence consisting of three consecutive keypresses of the index, middle, ring finger or pinkie of the right hand. In all of our four experimental conditions, these two sets – L1 and L2 – were learned in two notably different encoding situations, both including a variety of remarkably different intentional and incidental stimuli. This contrasting environmental manipulation between L1 and L2 was meant to induce attention on these intentional and incidental contextual stimuli.

We then created four different test conditions. The *change group*, constituting the first test condition, switched the intentional and incidental test context completely back to the L1 encoding situation, including the L1 response keys then being the test response keys. This group, thus, re-established access to the representation of the L1 encoding context. The *no change group* as the second test condition remained at test identical to the L2 encoding situation, including the L2 response keys then being the test response keys. So, there was no intentional or incidental contextual change in this group from L2 encoding to the test situation. The remaining two test groups, *neutral change group* and *neutral no change group* were designed similarly. The *neutral change group* also switched the incidental test context from L2 encoding back to the L1 encoding context, but not the intentional test context. The complete displayed test cues and instructions – fonts and used colors – were held neutral, as compared to L1 and L2. The same neutral colors and fonts were used at test in the *neutral no change group*, wherein the incidental test context remained at the L2 context, despite these changes in the visual stimuli. In both *neutral* groups, the visual stimuli thus changed to novel intentional cues (fonts, colors, test cues), that is, these stimuli did not match either L1 or L2. Beside this mismatch in the intentional test stimuli set, the *neutral change group* additionally changed the used PC, display orientation, response keys and keyboard position back to the ones used for L1 learning. For the *neutral no change group* these incidental stimuli remained the same as for L2 learning (see ***Figure 1***).

With regard to intentional learning, recently, the theory of *the two faces of memory retrieval* (e.g., Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b) posited that context changes between encoding and test modulate how recall performance develops over recall trials. Recall performance either improves or worsens over test trials because the first trials of a test either facilitate subsequent retrieval of further items (via re-establishing access to a representation of the common encoding context) or inhibit further items (when the context did not change). Bäuml and Samenieh (2012a, 2012b) proposed a two-factor account, explaining why retrieval can be a self-limiting process in the absence of a contextual change, but be self-propagating in its presence. According to their account, the original encoding context is deactivated after a change in external or internal context. Initial retrieval of some of the original context items then reactivates this context, and as a consequence, retrieval of the other context-related items becomes easier over the course of retrieval attempts, self-propagating. In the absence of a context change, the original encoding context remains active and initial retrieval of some related items can inhibit or block access to the items of the other context. Retrieval becomes a self-limiting process. For the present investigation, therefore, we also analyzed how recall performance developed over test trials by comparing the first with the second half of the test trial responses.

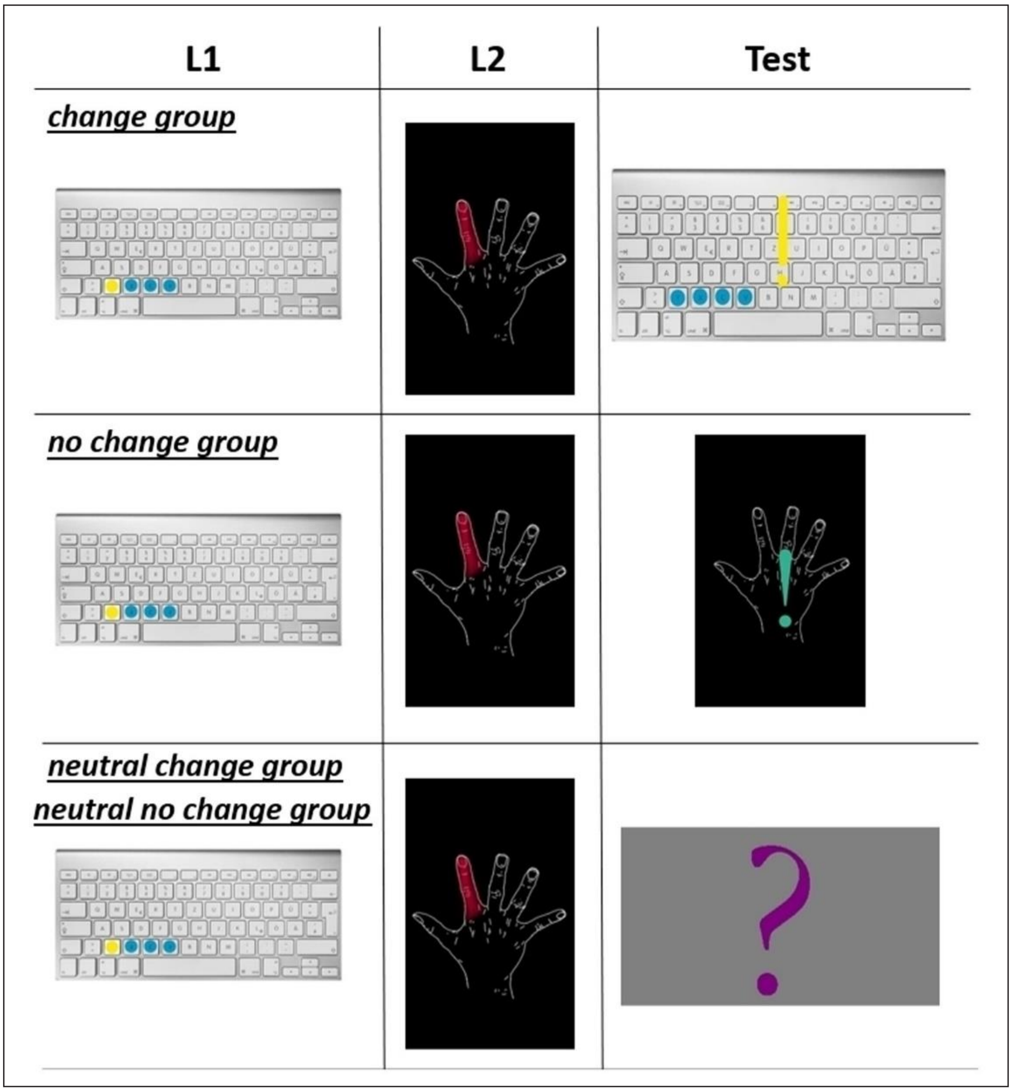

Figure 1 Diagram of the visual intentional cues in our four experimental groups at L1, L2 and at test, groups and experimental phase labeled and separated in boxes. Pictures show an example of the groups corresponding displayed intentional stimuli at encoding and test, including their display orientation (vertically vs horizontally). For the two neutral groups a question mark highlighted each input task at test, for the other two groups an exclamation mark demanded for the sequences input. Colors at test in the change and no change groups were held in the corresponding group test context, colors for the neutral groups were new ones as compared to L1 and L2 (see the Material section). The neutral groups differed with regard to used PC, display orientation, response keys and keyboard position from each other, which were the same as study of L1 (*change group*) or L2 (*no change group*).

According to Bäuml & Samenieh's (2012a, 2012b) *two faces* account, we expected recall for the *no change group* as being a self-limiting process. For the absence of a contextual change, the L2 encoding context should remain active and initial retrieval of some items related to this context should inhibit or block access to further items. Initial recall should be high but decline subsequently. In contrast, recall in the *change group*, wherein context changed after L2, should be self-propagating. Initial retrieval of some of the L1 context items should reactivate this context, and subsequent retrieval of the other L1 context related items should become easier. So, according to the *two faces* account (e.g., Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b), we expected initial recall in the *change group* to be lower, but subsequently increasing or at least stable, not declining, as we expected it to be in the *no change group*.

We expected recall in the *neutral no change group* as also being a self-limiting process. Recall for this group, wherein we switched the visual stimuli to neutral, should behave similarly to the *no change group*. The maintained environmental L2 context features at test should not get into a cue conflict with a displayed neutral stimulus set. Neutral visual cues also should not suffice to induce a context change. The test, furthermore, used the same response keys as L2. So, the L2 encoding context should remain active. Initial retrieval of some items related to this context should inhibit or block access to further items. Initial recall should be high but decline subsequently.

With the *neutral change group,* we explored whether the L2 context would even remain active with a further switch in incidental stimuli. Thus both, the environmental feature set and the response keys, were switched back to L1. The (intentional and incidental) displayed stimuli were the same as in the *neutral no change group*. So, this group constitutes a not completely reinstated condition. These neutral display stimuli here might prevent a contextual change back to L1, that is, switched environmental features and the response keys from L1 might not suffice for a contextual change back to L1. So, the L2 encoding context as the last context should remain active. Initial retrieval of some items related to this context then again would inhibit or block access to further items.

METHOD

PARTICIPANTS

One-hundred-and-thirty-six students (mean age = 22.9) at the PH Ludwigsburg, University of Education, participated in the experiment. Each of the four experimental groups, thus, contained thirty-four students. An a priori calculation of the required sample size with $1-\beta = .9$, $\alpha = .05$ and an estimated effect size based on prior motor memory results (e.g. Tempel & Frings, 2016, 2017, 2019) of $f = .2$ resulted in one-hundred-twenty-eight participants. We conducted the experiment in groups by three participants and also ran some more participants to account for drop outs. All students were paid ten Euros each for their participation.

DESIGN

We manipulated the test context by comparing four groups that differed with regard to matching or, respectively, non-matching intentional and incidental stimuli. In the *no change* group, intentional stimuli (i.e. visual stimuli representing the to-be-performed sequences) and incidental stimuli (i.e. used PC, display orientation, instructions fonts and colors, response keys, and keyboard position) remained the same as during learning of L2, whereas intentional as well as incidental stimuli switched back to those present during learning of L1 in the *change* group. In a third and fourth group, no intentional stimuli from either L1 or L2 were repeated but, instead, neutral visual stimuli prompted execution of the learned motor sequences in these *neutral* groups. Incidental stimuli remained the same as during learning of L2 in the *neutral no change* group but switched back to those present during learning of L1 in the *neutral change* group.

MATERIAL

The experiment was conducted using different PCs with standard German QWERTZ keyboard layouts. The software PsychoPy in version 1.90.1 (Peirce et al., 2019) served for running the experiment. The items consisted of two lists of eight three-finger movements of the index-, middle-, ring finger or pinkie of the right hand (see Appendix A). The three-finger movements were to be enacted on the second lower row of the horizontally orientated keyboard (keys were Y, X, C and V) for L1. L2 keyboard position was flipped ninety degrees, so the sequential finger movements had to be enacted on the second lower row of the number pad, keys were Num_Decimal, Num_3, Num_6 and Num_9.

To create two contextually distinct encoding conditions, we varied several physical features. During the learning phase, the intentional stimuli, i.e. the animation of the finger sequences, were in color highlighted keyboard buttons for L1 and in color highlighted fingers in a drafted symbolic hand for L2, indicating the order of the sequence enactment in color highlighted animation (see ***Figure 2***).

We used two nearest to the complementary different colors for each list. Additionally, the used colors for L1 were different to the ones for L2. L1 move indicating color was yellow, not moving keys were blue. Thus, the four reaction keys Y, X, C, and V were highlighted on the display throughout the whole learning trial. L2 move indicating color was red and green for fingers side by side. The visual intentional stimuli, thus, were the “moving” keys on a grey symbolic Mac-Keyboard in L1 or the “moving” fingers in a drafted symbolic hand in L2, both in a displayed color animation followed by a blank screen pause, before the next sequence gets animated. At the beginning of the animation, a picture of the keyboard including the four reaction keys marked in blue or a drawing of the corresponding hand appeared for 1500 milliseconds (ms). Then, an animation of the keys or the fingers in the hand showed three consecutively

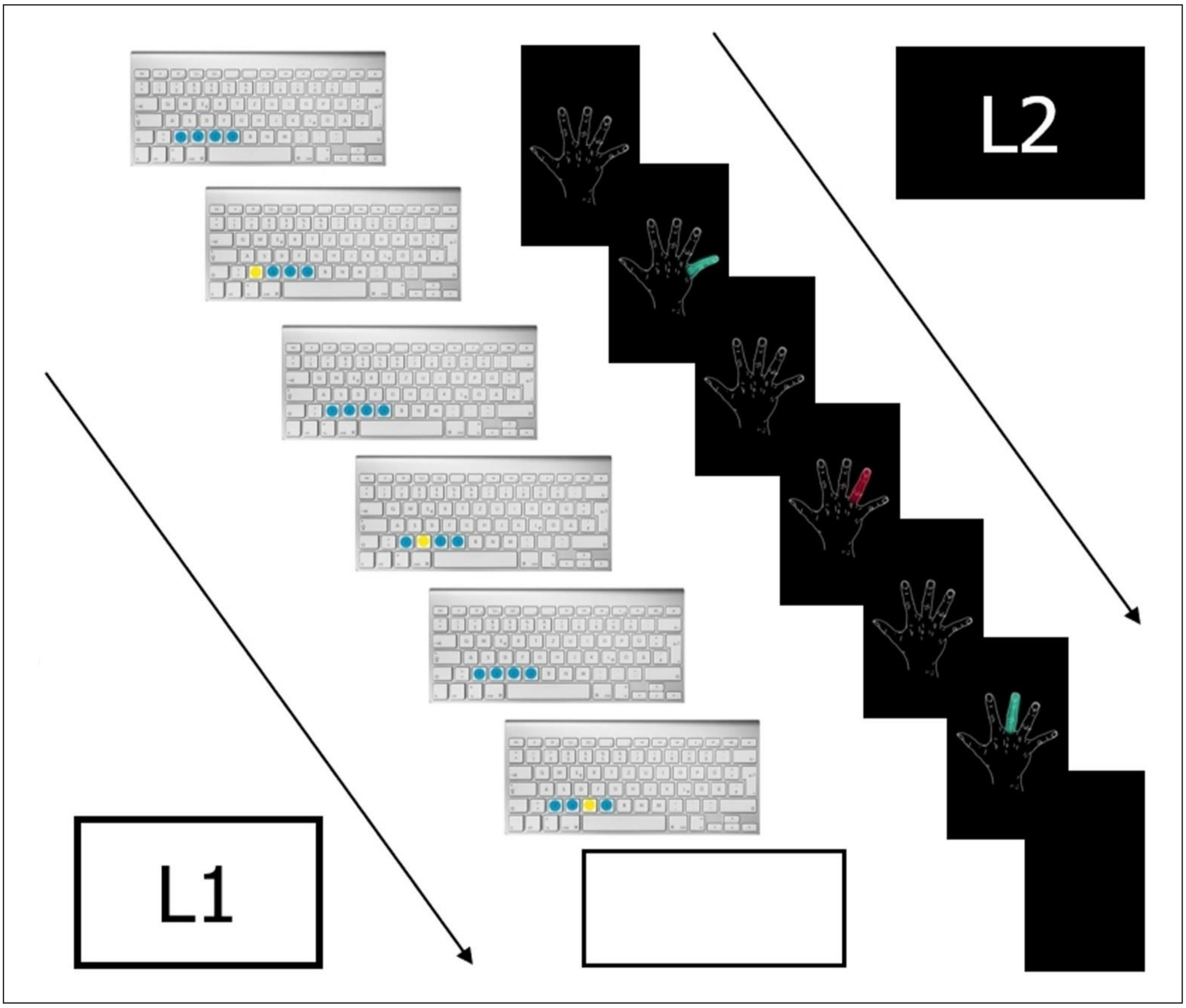

Figure 2 The Figure depicts one displayed symbolic item trial for both, L1 (left side) and L2 (right side). L1 intentional stimuli were the "moving" keys on a grey symbolic Mac-Keyboard. L2 intentional stimuli were the "moving" fingers in a drafted symbolic hand. Both items were displayed in a colored animation followed by a blank screen pause. Participants had to enter this sequence then, before the next sequence gets animated. At the beginning of the animation, a picture of the keyboard including the four not moving reaction keys marked in blue or a drawing of the corresponding hand appeared for 1500 milliseconds (ms). Then, an animation of the keys or the fingers in the hand showed three consecutively flashing keys or fingers. The index finger in L2 was highlighted in dark red, middle finger was colored in a light green, the ring finger was colored dark red again, pinkie again in light green; 200 ms per colored finger flash followed by 200ms for the uncolored hand drawing before the next moving finger. All moving keys in L1 were highlighted in yellow, the three not moving keys in between were given in blue; also 200 ms per color flash followed by 200ms for the four blue (not moving) keys before the next colored key. Once the animation disappeared, participants could perform it immediately by sequentially pressing the three corresponding keys.

flashing keys or fingers. The index finger in L2 was highlighted in dark red, middle finger was colored in a light green, the ring finger was colored dark red again, pinkie again in light green; 200 ms flashing the color highlighted finger followed by 200ms for the uncolored hand drawing before the next "moving" finger. All move indicating keys in L1 were highlighted in yellow, the other three response keys in between were given in blue. Each yellow highlighted key plus the three not moving (blue) keys was flashing 200 ms, followed by 200ms for the four blue (i.e. not moving) response keys before the next yellow highlighted key. Once the animation disappeared, participants could perform it immediately by sequentially pressing the three corresponding keys. Feedback about the performed sequence was given for 800 ms, indicating wrong finger movements by displaying: “Fehler!” (English: “Error!”) in the center of the screen. Error feedback was given to foster encoding accuracy, following previous studies with the same kind of learning material (e.g. Tempel & Frings, 2016, 2017, 2019). Correctly entered sequences were followed by 800 ms blank screen instead. After further 800 ms blank screen, the next trial started (see ***Figure 2***).

We also varied several incidental features between lists. L1 background color was white, instructions were given in a black font, the symbolic keyboard picture was given in a grey Mac-Laptop-Layout. L2 background color was black, instructions and drafted symbolic hand were given in a white font. L2 display orientation was vertical, L1 display was in a horizontal position. Keyboard orientation for L1 was horizontal, L2 keyboard orientation vertical. Moreover, in L2 the keyboard itself was placed on a small shelf of that height, that participants could reach the response keys only in a slight downward position of their hand, in which they were told to leave their elbow on the table during the whole learning procedure and their fingers just over the keys. On a (standard) horizontal positioned keyboard (L1) the hand has a slight upward position. The experimenter explained and supervised this uncommon hand position. Participants then were instructed not to focus on their hand in the following learning phase but on the displayed animation instead and to keep the hand in this position. Finally, the whole separated working place for L2 had a ninety-degree shift compared to L1 (see ***Figure 3***).

PROCEDURE

The experiment consisted of three phases: L1 learning, L2 learning and a final memory test. First, general instructions were given on the computer screen and face-to-face verified by the experimenter. Participants then had a practice trial of two out of the lists items, to become familiar with the sequence animation and the corresponding response keys. Akin to Wright & Shea (1991), participants were instructed to use the intentional stimuli for the encoding of the sequential finger movements, but the incidental stimuli were not mentioned at all. Afterwards L1 learning began. All eight L1 items were learned eight times in succession, in a random order. Subsequently a ten-minute break began, wherein participants were demanded to leave the room. L2 learning then took place in a different separated working place in the same room on another PC that had a spatially ninety-degree rotation, compared to the L1 working place. All eight L2 items also were learned eight times in succession in a random order, then the second ten-minute break took place. Participants again were instructed to leave the room after L2 learning for ten minutes, as they did after L1 learning. So, both learning trials had the same procedure. Then participants were tested with either the same or different incidental and/or intentional contextual cues compared to L2 learning, depending on their experimental group assignment.

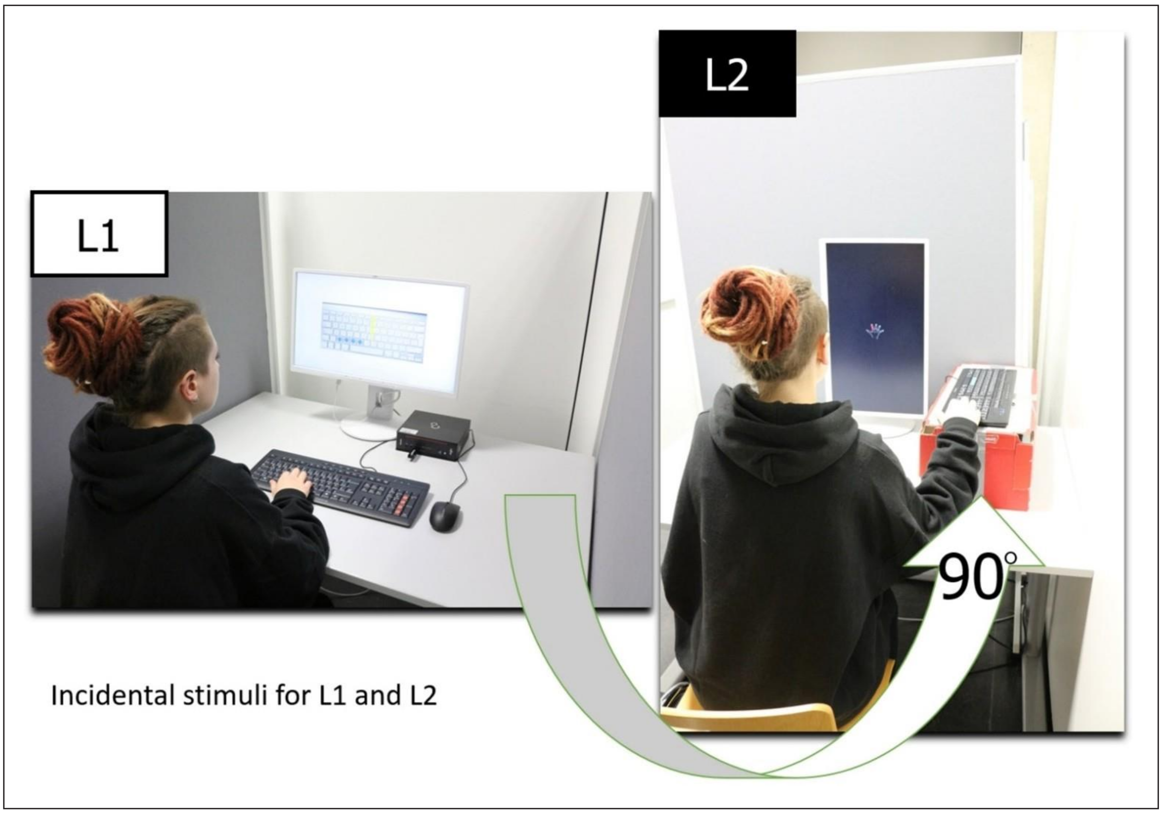

Figure 3 Photographies illustrating the different L1 and L2 incidental and intentional stimuli. L1 picture shows a change group participants' test trial. L2 picture shows a learning trial.

In this final test phase, we had a *change group* condition, wherein we induced a(n) (external) context change, by switching the test context back to the L1 intentional and incidental stimuli feature context, or we maintained the L2 intentional and incidental stimuli feature context, constituting thereby a *no* (context) *change group* condition. Two further conditions were designed along this *change* or *no change* pattern, that also differed in their reinstated or maintained features. The third condition, *neutral change group*, also switched the test context features back to the L1 incidental context but with neutral visual stimuli. The complete displayed test instruction and test cue set here was held in a neutral color and font as compared to the ones used in L1 and L2, but the test used the same PC, display orientation, response keys and keyboard position as L1. The fourth condition, *neutral no change group*, maintained the L2 incidental context features at test but also had neutral visual stimuli – the same ones as the *neutral change group*. So, the complete displayed test instruction and test cue set here also was held in a neutral color compared to the ones used in L1 and L2, but the test used the same PC, display orientation, response keys and keyboard position as L2.

Recall for all sixteen items (both lists) then was assessed in a self-paced free recall test. Recall was instructed explicitly in any order the items come to mind, no matter what list the items belonged to, but with the intention to recall all items of both lists. Each sequence input (three keys pressed in succession) was prompted by the corresponding test cue (a question mark or exclamation mark in front of visual stimuli matching L1, visual stimuli matching L2 or a plain grey). Test trials were separated by 500 ms blank screen. The free recall test was not limited in time, but participants had to enter sixteen sequences (consisting of three consecutive keypresses each).

RESULTS

To inspect the overall recall performance under the perspective of the *two faces* account (Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b), we divided the sixteen serial recall positions of our four experimental conditions into two groups. The serial recall of the first eight recalled items are labeled T1 in the following. Accordingly, recalled items of the serial positions nine to sixteen, the second eight recalled items, are labeled T2 in the following.

We then conducted a 4 (*no change*, *neutral no change*, *neutral change*, *change*) *groups* × 2 (T1, T2) *recall* ANOVA with repeated measures on the last factor. The main effect of *groups* was not significant, with $F(3, 132) = 2.34$, $p = .076$, $\eta_p^2 = .051$. The main effect comparing T1 and T2 *recall* was significant, with $F(1, 132) = 43.25$, $p < .001$, $\eta_p^2 = .247$. The interaction *groups* × *recall* was significant, $F(3, 132) = 2.84$, $p = .041$, $\eta_p^2 = .061$, caused by the *change group*, which showed a different result pattern compared to the other three group conditions. All T1 and T2 recall differences for these three groups were significant, but the *change group* showed no such reliable difference (see ***Table 1***).

Table 1 t-tests for T1 and T2 recall differences for our four experimental groups

condition group	*t*	df	*p*	significance
no change	5.1	33	<.001	**
neutral no change	3.2	33	0.003	**
neutral change	4.5	33	<.001	**
change	.94	33	0.36	n.s.

So, the recall pattern of the three experimental groups *no change, neutral no change,* and *neutral change* was similar, but these three groups differed remarkably from the recall pattern of the *change group*[1] (see ***Figure 4***).

1 In additional analyses, recall positions were divided into four blocks, each comprising four consecutive recall positions. When looking at the three groups *no change*, *neutral change*, and *neutral no change*, there was a strong linear trend indicating a decrease of recall success, $F(1, 99) = 96.01$, $p < .001$, $\eta_p^2 = .493$, which did not differ between groups $F(2, 99) = 1.184$, $p = .310$. Although there also was a linear trend in the *change group*, $F(1, 99) = 7.99$, $p = .008$, $\eta_p^2 = .195$, it was significantly weaker in contrast to the other three groups, $F(1, 134) = 5.60$, $p = .019$, $\eta_p^2 = .04$.

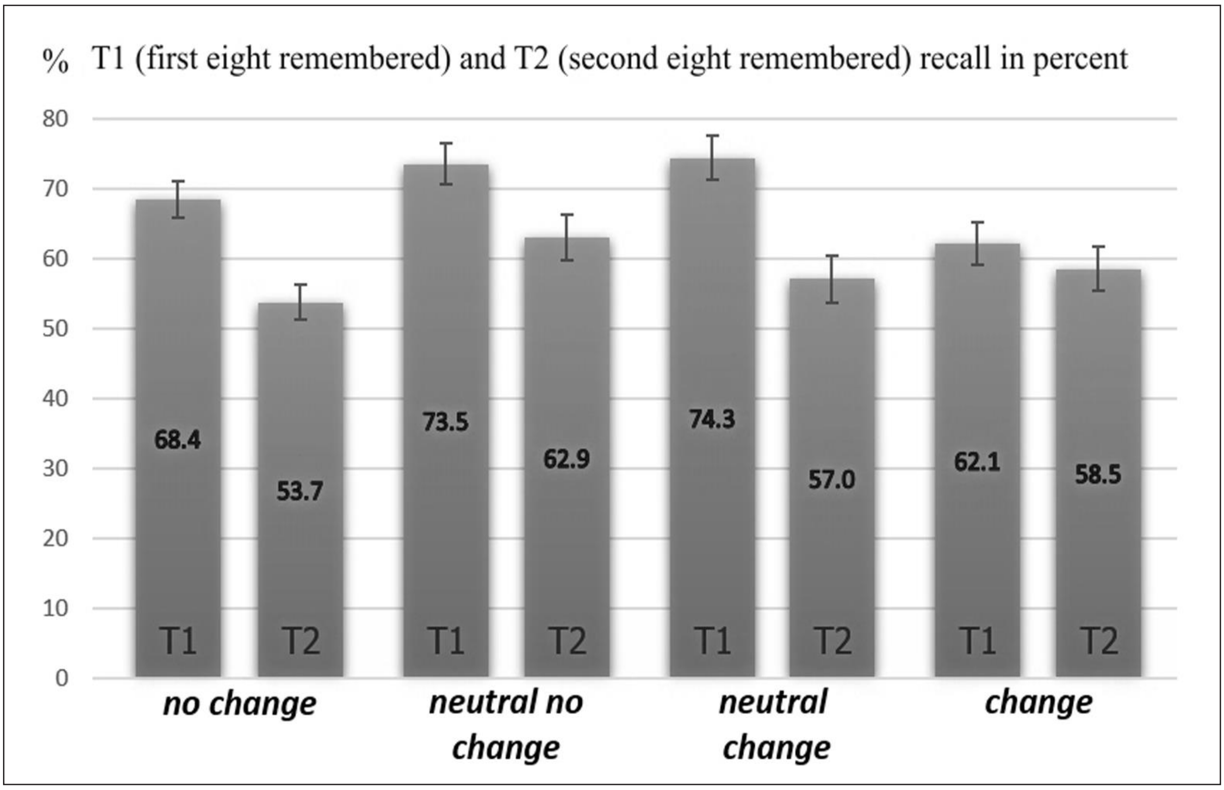

Figure 4 T1 and T2 recall rates of our four experimental condition groups in percent. Error bars represent ±1 S.E.M.

GENERAL DISCUSSION

The expected recall patterns for our two main conditions, the *no change* and *change group*, emerged. According to the *two faces* account of (context-dependent) retrieval (e.g. Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b), we expected recall for the *no change group* to be a self-limiting process. For the absence of a contextual change at test, the L2 context should remain active and initial retrieval of some items related to this context should inhibit or block access to other items. Initial recall should be high but decline subsequently. This pattern was observed.

Recall for the *change group*, in which intentional and incidental stimuli changed after L2 completely back to the L1 context, should be self-propagating for the presence of a (true) context change at test. Initial retrieval of some items then should facilitate subsequent retrieval. We expected initial recall in the *change group* to be lower, but subsequently staying at least nearby stable, not declining as in the *no change group*. This pattern was observed.

The *neutral no change group* and *neutral change group* showed the same recall pattern as the *no change group*. This suggests that the at test maintained L2 or reinstated L1 environmental context features in these groups did not to get into a cue conflict with a neutral (intentional and incidental) display stimuli set. Neutral display stimuli did not suffice to induce a context change. The test in the *neutral no* *change group*, furthermore, used the same response keys as L2. So, the L2 encoding context should remain active and initial retrieval of some items related to this context should inhibit or block access to further items. Initial recall should be high but decline subsequently. This pattern was observed.

A comparison of the recall pattern in the *neutral change group* with the *change group* showed the importance of the visual intentional (recall cues) and incidental stimuli (instructions font and colors, background color) set for the occurrence of a context effect. Only a complete change of intentional as well as incidental stimuli after L2, back to all features present during L1 learning, eliminated the typical pattern of a strong decreasing recall from T1 to T2, which suggests that only this combined mismatch was a true context change. This underlines the importance of the intentional as well as the incidental (visual) stimuli for the occurrence of a context-dependent memory effect and further shows the influence of intentional and incidental context features given at encoding and test for an intentional learning and recall setting of motor sequences. Moreover, the proposals of the *two faces* account of (context-dependent) retrieval (Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b) critically assume, that the degree of context change determines the relative contributions of the mechanisms blocking/inhibition and contextual retrieval. That means, if the degree of context change is low or moderate only, the beneficial effect from T1 on T2 recall may be low or even absent. We reported a detrimental effect from T1 on T2 for our *neutral no change group* and the *neutral change group*, which also could be labeled *small context change* conditions. For our *change group* we reported a neutral effect. This pattern fits with the *two faces* account, implying that the size of the induced contextual effects for our *change group* appears to be moderate only, so that there is reason to expect a neutral rather than a beneficial effect for this group.

Ruitenberg et al. (2012) in their incidental learning setting suggested, that the effects of context in the discrete sequence production task not only reflect a facilitation of retrieval due to reinstatement, but also the learning of an effective dealing with irrelevant stimuli, what they refer to as context-dependent filtering. The switched intentional and incidental stimuli in our intentional motor skill acquisition study were used to accentuate a contextual shift. So, there was no way of filtering them out, for they defined the very context itself. If they are to be labeled, then they are rather distracting than irrelevant. Laub & Frings (2018) found a distractor-based action control effect that was modulated by encoding specificity. The distractor-based retrieval process in their experiment depends on the contextual similarity between the encoding and the retrieval context. Laub & Frings (2018) found clear evidence for the encoding specificity of this process. Distractor-based retrieval was found only in conditions with the same number of distractors in the prime and in the probe, if the encoding and retrieval context were contextually similar. Solely for conditions with the same number of distractors in the prime and the probe the typical pattern indicating distractor-based retrieval occurred. If the number of distractors changed between the encoding and retrieval context, no distractor-based retrieval occurred. This is similar to our observed results. Only for the condition with the identical "distracting" intentional and incidental stimuli at encoding and test – our *change group* – a true context change emerged and the expected recall pattern according to theory of *the two faces of memory retrieval* (e.g. Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b) occurred.

Wright & Shea (1991) showed in their Experiment 2, that changes in the intentional and incidental stimuli given at test within a reduced task difficulty setting (by switching from four- to three-key sequences) did not disrupt motor performance any more. Participants were able to perform the three-key sequences even in the absence of any intentional stimuli (third condition). This indicates developed (strong) associations between the incidental stimuli and the sequences that could be used at retrieval (in case of a cue conflict), even though participants just were instructed to attend to the intentional stimuli as an acquisitional aid. Our results also suggest developed strong associations between our incidental stimuli and the sequences, leading to a perception of the respective lists sequences as two different contexts that could get reinstated at test.

Further studies on these observed contextual recall dependencies of motor sequences could clarify the role of the hand position and, more generally, which incidental and intentional features are necessary at all to result in contextual effects? Future work may also like to elucidate the role of contextual effects for retrieval dynamics of motor sequences when context is changed more drastically. Under such conditions of a drastic context change, even a beneficial effect from T1 to T2 should arise, at least if the theory of *the two faces of memory retrieval* applies to the present situation and T1 retrieval attempts last long enough to facilitate contextual accessibility, i.e. the lists are long enough.

Taken together, further research is needed to clarify the role of intentional and incidental context features as contributors for a perceived environmental context change. The present results suggest that only a combined mismatch was a true context change.

Our results have implications on the practical side of intentional motor skill acquisition. Imagine, for example, a school orchestra and their music teacher learning pieces of music for the annual school concert. Learning all the concert pieces of music in one and the same environmental context, which is also rather similar than different to the test context (i.e. the concert hall), will result in a high accessibility of the trained motor skills at that annual school concert. Performance there will show less errors, if the "test" environment will not be perceived as an environmental context change as compared to the learning environment.

APPENDIX A

Items.

ITEM	FIRST FINGER	SECOND FINGER	THIRD FINGER
1	index finger	middle finger	pinkie
2	index finger	pinkie	ring finger
3	middle finger	ring finger	pinkie
4	middle finger	ring finger	index finger
5	ring finger	index finger	pinkie
6	ring finger	index finger	middle finger
7	pinkie	index finger	middle finger
8	pinkie	ring finger	index finger

L1-Items

ITEM	FIRST FINGER	SECOND FINGER	THIRD FINGER
1	index finger	ring finger	middle finger
2	index finger	ring finger	pinkie
3	middle finger	index finger	ring finger
4	middle finger	index finger	pinkie
5	ring finger	pinkie	index finger
6	ring finger	pinkie	middle finger
7	pinkie	middle finger	index finger
8	pinkie	ring finger	middle finger

L2-Items

DATA ACCESSIBILITY STATEMENT

https://osf.io/knqag/?view_only=0847a7bbd3964d62bf504ec6e1cd04fe

ETHICS AND CONSENT

All procedures performed in the current experiment accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration, its later amendments or comparable ethical standards. All participants gave informed consent at the beginning of the experiment.

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COMPETING INTERESTS

The authors assert, that there are no competing interests to declare.

REFERENCES

Bäuml, K.-H. T. (2019). Context retrieval as a critical component in selective memory retrieval. *Current Directions in Psychological Science*, *28*, 177–182. DOI: *https://doi.org/10.1177/0963721419827520*

Bäuml, K.-H. T., & **Samenieh, A.** (2012a). Selective memory retrieval can impair and improve retrieval of other memories*. Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(2), 488–494. DOI: *https://doi.org/10.1037/a0025683*

Bäuml, K.-H. T., & **Samenieh, A.** (2012b). Influences of part-list cuing on different forms of episodic forgetting. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *38*(2), 366–375. DOI: *https://doi.org/10.1037/a0025367*

Bower, G. H. (1981). Mood and memory. *American Psychologist*, *36*(2), 129–148. DOI: *https://doi. org/10.1037/0003-066X.36.2.129*

Godden, D. R., & **Baddeley, A. D.** (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology (1975)*, *66*(3), 325–331. DOI: *https://doi. org/10.1111/j.2044-8295.1975.tb01468.x*

Isarida, T., & **Isarida, T. K.** (2007). Environmental context effects of background color in free recall.

Memory & Cognition, *35*, 1620–1629. DOI: *https://doi.org/10.3758/BF03193496*

Laub, R., & **Frings, C.** (2018). Distractor-based Retrieval in Action Control: The Influence of Encoding Specificity. *Psychological Research* (pp. 1–9). DOI: *https://doi.org/10.1007/s00426-018-1082-8*

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo, H., Kastman, E., & **Lindeløv, J.** (2019). PsychoPy2: experiments in behavior made easy. *Behavior Research Methods*, *51*, 195–203. DOI: *https://doi.org/10.3758/s13428-018-01193-y*

Pointer, S. C., & **Bond, N. W.** (1998). Context-dependent memory: Colour versus odour. *Chemical Senses*, *23*(3), 359–362. DOI: *https://doi.org/10.1093/chemse/23.3.359*

Psychopy, free Psychology software in Python. Downloadable at: *https://www.psychopy.org/download. html*

Rand, G., & **Wapner, S.** (1967). Postural status as a factor in memory. *Journal of Verbal Learning and Verbal Behavior*, *6*, 268–271. DOI: *https://doi.org/10.1016/S0022-5371(67)80107-5*

Ruitenberg, M. F. L., De Kleine, E., Van der Lubbe, R. H. J., Verwey, W. B., & **Abrahamse, E. L.** (2012). Context-dependent motor skill and the role of practice. *Psychological Research*, *76*, 812–820. DOI: *https://doi.org/10.1007/s00426-011-0388-6*

Sahakyan, L., & **Smith, J. R.** (2014). "A long time ago, in a context far, far away": Retrospective time estimates and internal context change. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(1), 86–93. DOI: *https://doi.org/10.1037/a0034250*

Smith, S. M. (1985). Background music and context-dependent memory. *The American Journal of Psychology*, *98*(4), 591–603. *https://www.jstor.org/stable/1422512*. DOI: *https://doi. org/10.2307/1422512*

Smith, S. M., Glenberg, A., & **Bjork, R. A.** (1978). Environmental context and human memory. *Memory & Cognition*, *6*, 342–353. DOI: *https://doi.org/10.3758/BF03197465*

Tempel, T., & **Frings, C.** (2016). Directed forgetting benefits motor sequence encoding. *Memory & Cognition*, *44*, 413–419. DOI: *https://doi.org/10.1080/09658211.2015.1059858*

Tempel, T., & **Frings, C.** (2017). Retrieval-induced forgetting is retrieval-modality specific: Evidence from motor memory. *Cognition*, *162*, 143–152. DOI: *https://doi.org/10.1016/j.cognition.2017.02.005*

Tempel, T., & **Frings, C.** (2019). Testing enhances motor practice. *Memory & Cognition*, *47*, 1270–1283. DOI: *https://doi.org/10.3758/s13421-019-00932-6*

Wright, D. L., & **Shea, C. H.** (1991). Contextual dependencies in motor skills. *Memory & Cognition*, *19,* 361–370. DOI: *https://doi.org/10.3758/BF03197140*

4.2. Artikel 2: Selective directed forgetting of motor sequences

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Selective directed forgetting of motor sequences

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ABSTRACT

We examined selective directed forgetting in motor memory using a new variant of a three-list approach, to distinguish between accounts of directed forgetting. Participants consecutively studied three lists (L1, L2, and L3) of four sequential four-finger movements each. After studying L2, participants in the *forget group* were instructed to selectively forget the just studied four items of L2 but to retain the previously studied four items of L1, whereas the *remember group* did not receive any forget instruction for L2 but was encouraged to retain the items of both lists. In addition, we switched (*switch groups*) or repeated the items-enacting hand (*no-switch groups*) between L2 and L3 for a manipulation of post-forget-cue material competition for L2. A final memory test assessed recall performance for all three lists. Selective directed forgetting (lower L2 recall in the *forget group* as compared to the *remember group*) only occurred if the same hand was used for L2 and L3 (high interference between L2 and L3 encoding) whereas no selective directed forgetting occurred if the hand switched between L2 and L3 (low interference between L2 and L3 encoding). These results suggest that an inhibitory mechanism caused (selective) directed-forgetting costs that was triggered when items studied after the forget instruction had the potential to interfere with already stored items (i.e. were to be enacted by the same hand). When subsequently studied items pertained to the other hand no directed-forgetting costs occurred.

Keywords:
List-method directed forgetting
Inhibition
Context change
Selective rehearsal

1. Introduction

Updating memory content is an important issue for everyday memory access. When stored information becomes outdated, a mechanism is necessary to weaken that outdated content and grant access on what is relevant now (e.g. a new telephone number after moving to a new apartment). Memory control comprises (among other things) intentionally forgetting no longer relevant information. Over decades, a multitude of studies has demonstrated the human ability for directed forgetting, using various kinds of item materials (for a review see MacLeod, 1998). However, there is a still ongoing debate in the literature about the underlying cognitive processes. A particularly strongly debated issue has been whether directed forgetting involves inhibition, that is, an active suppression of information that weakens subsequent accessibility. The present investigation addressed this question by adapting an experimental paradigm focusing on how selective effects of directed forgetting can be. Using sets of newly acquired motor sequences as items provided measures of directed forgetting that were of a non-verbal nature. Thus, a potential suppression of certain items was targeted at solely episodically defined categories, avoiding associations with semantic memory representations. This material, therefore, enabled a purer assessment of whether inhibition may be used intentionally to target specific items as compared to word materials that typically possess many associations to semantic and/or autobiographic memory. In addition, motor sequences allowed to test a specific assumption on the interference-dependence of inhibition by making use of body-based interference potentials (interference of movements performed with the same effector as opposed to a different effector, in particular).

A standard experimental paradigm for investigating intentional forgetting is the list method of directed forgetting (LMDF; Bjork, 1970). Participants in this paradigm typically study two word lists. After the first list, half of them are cued to forget this list (*forget group*), whereas the other half simply is informed about another upcoming list (*remember group*). Participants in the *forget group* are told, for example, that the computer program had a malfunction or that the first list just has been a "warming up", and that the "real experiment" will start with the second list. In any case, the first list for them is cued to forget. Then all participants learn the second list. Memory for both lists is assessed in a final test, irrespective of the preceding instructions. Participants in the *forget group* typically remember fewer items from the first list (*costs*) but show better memory performance for the second list (*benefits*) as compared to the *remember group*. This LMDF standard paradigm has found use in a multitude of studies across a wide variety of learning conditions and study materials (MacLeod, 1998). Despite the extensive use of the standard LMDF, this approach is relatively unspecific because the forget instruction entails a complete list, whereas updating memory content in everyday life is more often a specific process, targeting a specific to-be-forgotten content.

This issue of selectivity has been addressed by an adaption of LMDF, instructing the *forget group* only to forget one part of the so far encoded material but to remember the rest. A study by Sahakyan (2004) was the first to use a three-list variant of the LMDF paradigm. Participants were assigned to one of three conditions with different instructions: to remember all three lists, to forget list one but to remember list two and three, or to forget list two but to retain list one and three. They were initially told that they would study three word lists in succession for a later memory test and were informed that each list would be followed by an instruction that specifies whether or not that list is to-be-remembered. Results showed effective listwise forgetting but forgetting extended to list one when the forget instruction followed list two. Thus, no selective forgetting occurred but costs for both lists studied before the forget instruction.

In contrast, Delaney et al. (2009) demonstrated selective directed forgetting in a two-list approach containing relevant and irrelevant information within one list. Participants studied sentences about two characters, Tom and Alex, presented in an alternating order (e.g. "Tom watched television", "Alex brushed his teeth"). A subsequent forget instruction concerning only one of the two characters induced selective costs for the respective sentences in a recall test. This pattern of results has been replicated in several studies (Aguirre et al., 2020; Aguirre et al., 2014; Aguirre et al., 2017; Gómez-Ariza et al., 2013; for a failed replication however see: Storm et al., 2013).

Kliegl et al. (2013) scrutinized whether directed forgetting can be selective in a three-list design when employing short precue lists, whereas Sahakyan (2004) had used relatively long lists (twelve items each). Also different to the Sahakyan (2004) study, where each list was followed by its cue instruction, *forget group* participants here were cued after L2 to forget L2 and to keep remembering L1. In addition, Kliegl et al. (2013) scrutinized whether selectivity in the three-list task varies with the level of discriminability of the precue lists L1 and L2, "assuming that with a high level of discriminability between the irrelevant precue list and the relevant precue list, selectivity may be high, and with a low level of discriminability, it may be low" (p. 454). Categorical features to vary lists discriminability were the font color of the items (Experiment 1) and the auditory presentation of the two lists by either the same voice or two different voices (Experiment 2). Moreover, they wanted to examine whether selectivity in directed forgetting differs between the three-list and the two-list task (Experiment 3). Kliegl et al. (2013) were the first to demonstrate selectivity in a three-list task. Selective costs for only the second but not the first list were observed, independently of modality of item presentation, the level of discriminability of the precue lists, or the type of the LMDF task used (see also: Kliegl et al., 2018).

1.1. *Competing explanations for selective directed forgetting*

The question of when and under which circumstances there will be selective directed forgetting costs pertains to the explanatory models of LMDF. The selective-rehearsal account (Bjork, 1970), as the first prominent (one-factor) model, assumed forget-cued participants to selectively rehearse (only) the to-be-remembered items, thereby producing the costs (and the benefits). In contrast, the retrieval-inhibition account (Geiselman et al., 1983) assumes costs to be produced by active inhibitory (executive) control processes, impairing access to the forget-list items. Finally, the context-change account (Sahakyan & Kelley, 2002) states that the forget cue induces a mental context change that impairs recall of the forget list at test due to a contextual mismatch between the encoding and the retrieval context. Recently, also two-factor models have been suggested, assuming the costs being caused by inhibition or context change, whereas the benefits (partly) reflect improved encoding (Pastötter et al., 2012; Sahakyan & Delaney, 2003).

Thus, seen from the more recent two-factor perspective, the question of selectivity in directed forgetting costs in LMDF is the question about inhibition and/or context change as the cause, i.e. a challenge for research is to disentangle the relative contributions of the assumed mechanisms. In fact, there are quite a number of selective directed forgetting studies that already have provided evidence for the inhibitory view. Gómez-Ariza et al. (2013) and Aguirre et al. (2014), using Delaney et al.'s (2009) stimuli and procedure, observed selective directed forgetting in their control samples for uncommon populations (adolescents diagnosed with social anxiety disorder and older adults). Both studies were motivated by the inhibitory assumption, that only the to-be-forgotten items will be targeted by the selective forgetting mechanism. Aguirre et al. (2017) also showed reliable selective directed forgetting in support of the idea of a flexible goal-oriented executive control mechanism just suppressing irrelevant precue information. Kliegl et al. (2018) were first to show, that selectivity in directed forgetting develops later during childhood and adolescence than nonselective directed forgetting, a result in line with the inefficient inhibition hypothesis of development (Bjorklund & Harnishfeger, 1990).

Two of the three explanatory models make the same predictions about selective directed forgetting costs in a three-list variant of LMDF, given the second list is to-be-forgotten and the first and third list are to-be-remembered. The selective-rehearsal account predicts selective directed forgetting costs in this variant of LMDF because it claims that irrelevant memories are omitted from the rehearsal process. Participants should rehearse solely the relevant items, regardless of their serial list position. The retrieval-inhibition account assumes the to-be-forgotten items (not only in this variant) as one subset of information and the to-be-remembered items as another one. So, one subset may uniquely become a target for active inhibition, in favor of the other, caused by the task demands (to forget L2). From the inhibitory view selective directed forgetting costs accordingly also should emerge in this variant. They could be seen as caused by an intentionally driven (inhibitory) control process, with the inherent assumptions that inhibition can selectively target specific memory contents and that it serves the purpose to enhance memory for to-be-remembered information (cf. Anderson, 2005). The context-change account, in contrast, assumes that a forget instruction triggers a mental context change, thereby lowering accessibility of all information studied before the forget instruction. Therefore, it predicts no selectivity of costs in this variant. Both precue lists - L1 and L2 - should be equally affected by the contextual encoding-retrieval mismatch, due to the forget-cue-elicited context change (after L2 encoding). Selective costs for the second list in the absence of costs for the first list, therefore, could not be explained in terms of the context- change account.

1.2. *The present study*

To sum up, two of the three explanatory models of directed forget- ting predict selectivity of costs in the three-list task of LMDF. However, an adaptation of this experimental paradigm for the use of motor sequences as item material allows us to distinguish between all three explanatory models in a novel way. Newly acquired sequential finger movements are of non-verbal nature and memorization takes place in solely episodically defined categories. Associations to semantic and/or autobiographic memory are much less likely than for words. This material, therefore, allowed to manipulate the degree of interference be- tween item lists independently from such associations but based on properties of the effectors involved in movement execution.

According to the inhibition theory by Anderson (2005), inhibition may follow the same principles across different memory phenomena (such as retrieval-induced forgetting and directed forgetting), one of them being interference dependence: Information is only inhibited when it has the potential to interfere with to-be-remembered content. With regard to directed forgetting this primarily concerns items studied after receiving a forget instruction and, correspondingly, it has been shown that no directed forgetting costs occur when there is no more item material to be studied or it is of insufficient amount (e.g. Conway et al., 2000; Pastötter & Bäuml, 2007, 2010). Here, we did not manipulate the interference potential in terms of the amount of post-cue studying but by either assigning the same or a different effector to movement execution, assuming a higher level of interference between motor sequences performed with the same hand as between motor sequences performed with opposing hands. Thus, we designed a particular motor modification of the LMDF task, that allowed us for distinguishing the final recall contribution between all three prominent accounts of LMDF.

Research on directed forgetting in motor memory is rare. Burwitz (1974) examined proactive interference and directed forgetting in short-term motor memory. Sahakyan and Foster (2009) compared directed forgetting for self-performed action phrases with verbally learned action phrases and found equivalent directed forgetting impairments for both. Most importantly for the present study, Tempel and Frings

(2016) examined directed forgetting of motor sequences. They conducted two experiments, adapting the list method for sequential finger movements as item material in a two-list approach. Each sequential finger movement consisted of four consecutive key presses from three fingers of the right hand. In this study, costs only emerged in Experiment 2, whereas there was a beneficial effect for L2 recall in the forget group in both experiments, suggesting that benefits were not a mere byproduct of costs. In contrast to Experiment 1, Experiment 2 involved a three-minute break between L1 and L2 along with different response keys for L2 as for L1. Perhaps, these changes facilitated an internal context change, thus producing directed forgetting costs. Alternatively, an inhibition of L1 might have been facilitated because the break and new response keys enhanced discriminability of the to-be-inhibited item set.

Here, we set out to examine whether directed forgetting could be selective in motor memory, using a particular three-list approach. Akin to Kliegl et al. (2013) we created three short sets (the lists) of four sequential finger movements, with each single finger-movement sequence (the item) consisting of four consecutive finger movements of the index, middle and ring finger of the left or the right hand (see Appendix A). Akin to Sahakyan (2004), each list presentation was followed by the lists' cue. L1 was to-be-remembered always. After learning of L2, participants either received a *forget* or a *remember* cue instruction for that list before they proceeded with L3. L3 also was to-be-remembered always. Yet, what is more, it has been shown that directed forgetting costs only occur if a forget instruction is followed by a sufficient amount of additional study of new material (Conway et al., 2000; Pastötter & Bäuml, 2007, 2010), suggesting that there must be a certain amount of interference between the to-be-forgotten and new information. With motor material, such interference probably is at a maximum when the same effector has to be used. Therefore, we manipulated interference between L2 and L3 by repeating (*no-switch group*) or switching (*switch group*) the lists enacting hand between L2 and L3 (see Fig. 1).

Using this particular motor task modification of the LMDF paradigm provides a tool for distinguishing between the three prominent accounts of LMDF. The results of the current experiment can differentiate between all three explanatory hypotheses: Finding non-selective directed forgetting costs of both - L1 and L2 - favors the context-change account, for the reason of the assumed (internal) contextual change due to the forget instruction after L2 learning. Finding selective directed forgetting costs for L2 only in the absence of an effector change (*no-switch group*) speaks in favor of the inhibition account, for the reason of the inhibitory account assumed necessary amount of interference between the to-be-forgotten and new information (cf. Anderson, 2005). And finally, finding selective directed forgetting regardless of whether there is an effector change or not favors the selective-rehearsal account.

Our hypothesis was to find support for the assumption that inhibition is involved in directed forgetting. Considering recent evidence in favor of the inhibitory view

(Aguirre et al., 2020; Kliegl et al., 2018), we expected an interaction of effector switch and forget-instruction for L2 memory performance, whereas L1 memory was expected not to depend on the L2 forget-instruction.

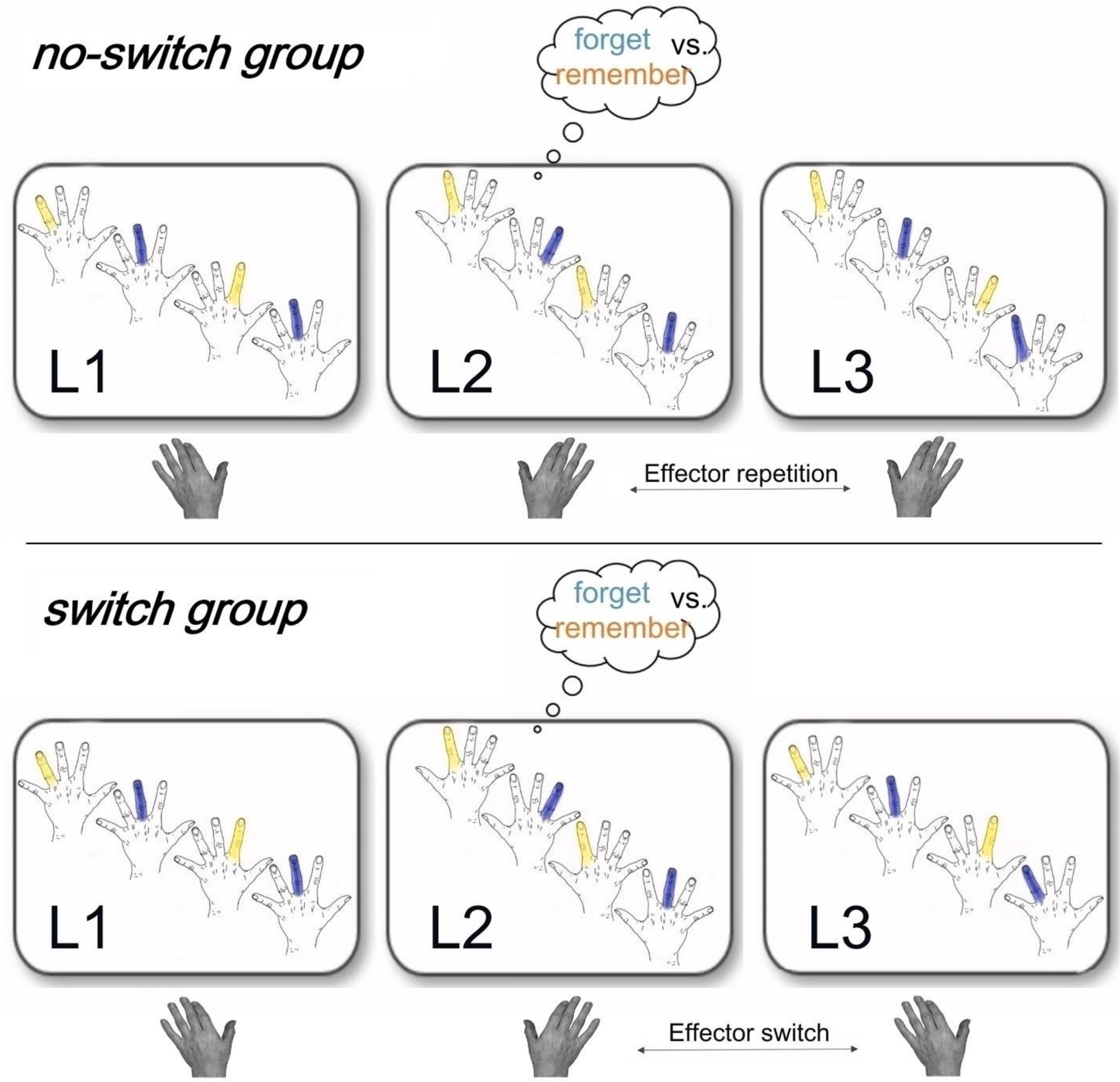

Fig. 1. Scheme of the experimental design including the first item of each of the three lists L1, L2 and L3 (see Appendix A for the complete lists). First experimental factor was effector repetition (*no-switch groups*) or effector switch (*switch groups*). Second experimental factor was the *remember* or *forget L2* instruction. This design resulted in four different experimental groups.

2. Method

2.1. *Participants*

One-hundred-and-forty-four psychology students (mean age 22.1) at the University of Trier participated in the experiment. They either received course credit or were paid six Euros for their participation.

2.2. *Design*

Two factors were manipulated between participants: effector switch after L2 (*no-switch* or *switch group*) and the instruction after studying L2 (*remember* or *forget group*).

2.3. *Material*

The experiment was conducted using Dell Optiplex 755 PCs with Eizo FlexScan S1901 monitors and standard German QWERTZ keyboards. The software PXLab (Irtel, 2007) served for running the experiment. The items comprised a total of twelve four-finger movements of the index-, middle-, or ring finger, in three sets of four items (L1, L2 and L3) for each participant. Across all conditions, L1 was to be enacted with the left hand always, L2 was to be enacted with the right hand always. Depending on the respective group assignment (see Fig. 1 or Appendix A), L3 items were enacted either with the right hand (*no-switch groups*) or with the left hand (*switch groups*). The four-finger movements were to be enacted on the second lower row of the keyboard, same keys for left- or right-hand enactment (keys were V, B, and N). During the learning phase, the lists were announced in numbers for 5 s (e.g. "now upcoming part 1 of the experiment"), then the participants were instructed to lay their three corresponding fingers of the (explicitly named) respective list hand on the three marked keys. Starting the list presentation by mouse clicking a checkbox, 3 s blank screen were followed by an animation of the first four-finger movement (item). At the beginning of the animation, a drawing of the corresponding hand appeared for 1000 milli-seconds (ms). Then, an animation of the hand showed four consecutively flashing fingers (the first finger was colored yellow, second finger was colored blue, the third finger was colored yellow again, the fourth finger was colored blue again, 200 ms per flash and 200 ms for the uncolored hand drawing between the fingers). Once the animation disappeared, participants could perform it immediately by sequentially pressing the four corresponding keys. Feedback about the performed sequence was given, fostering encoding accuracy. Wrong finger movements (key presses) were indicated by displaying: "Fehler!" (English: "Error!") in the center of the screen. After 3 s, the next trial started (see Fig. 2).

2.4. *Procedure*

The experiment consisted of three phases: learning, distractor task and final memory test. First, general instructions were given on the computer screen and summarized by the experimenter. Participants were informed about three upcoming parts (lists) of the experiment, each followed by an instruction to either forget or to remember the four sequences of that list for a final memory test. The experimenter ensured the comprehension of the task verbally. The participant then was onscreen informed about the upcoming part of the experiment (i.e. the list number) and told to place the respective three fingers (left hand or right hand) on the response keys. Clicking a checkbox started the list presentation. Participants had to consecutively press four keys in response to an animated hand movement graphic illustrating the item, that is, the order in which the four fingers were to be moved. Fifteen cycles per list were presented, each one containing the four items of that list in a random order. So, participants had sixty learning trials per list. Once the fifteen randomized cycles of the list's four items were finished, participants either received a remember or a forget instruction for this list, together with an indication of 30 s for rest and bodily relaxation before the next list. All three lists were given consecutively, always followed by the lists` cue instruction and the thirty-second break. L1 always was to be enacted with the left hand, L2 always was to be enacted with the right hand. So, in all four experimental groups there always was an effector switch from L1 to L2, enhancing list discriminability. L1 and L3 instructions for both lists in all four experimental groups always were to-be-remembered, the experimental groups differed only in the post-list cue instruction for L2 and the enacting hand for L3. One group received to-be-remembered instruction for L2 and enacted L3 also with the right hand (*no-switch - remember group*), the second group received to-be- forgotten instructions for L2 and enacted L3 also with the right hand (*no-switch - forget group*), see the upper section of Fig. 1. The remaining two experimental groups (i.e. the lower section in Fig. 1) also varied in the L2 instructions (remember or forget), but both groups enacted L3 then with the left hand. So, the third group received to-be-remembered instruction for L2 and enacted L3 with the left hand (*switch - remember group*), the fourth group received to-be-forgotten instructions for L2 and enacted L3 also with the left hand (*switch - forget group*). Forget-cued participants were post list cued that it was important to try to forget all the just learned sequences of List 2. Remember-cued participants just were encouraged to keep the lists in mind. We counterbalanced the assignment of the item sets to the list positions, resulting in six different order variations (counterbalanced between participants).

The final test phase encompassed three consecutive memory tests for all three lists in the order of their study. After a three-minute distractor task (a Sudoku puzzle) following the L3 thirty-second break, participants were informed about a now upcoming final memory test. Then instructions for L1 recall appeared. Participants were cued for the list recall by the displayed list number and instructed to place the corresponding hand (the same hand used during encoding) on the three response keys. They were instructed to type in all the four sequences of the cued list in any order they came to mind, but with the intention to type in all four items of the list. They were encouraged to guess, if they could not remember all four list items, because the computer expected the input of a four-finger sequence for four times before continuing. Then, an exclamation mark indicated to enter the first sequential four- finger movement (i.e. one item) of that list that came to mind. After pressing four different response keys (i.e. input of a sequential four-finger movement), 3 s blank screen followed, then the next exclamation mark indicated to enter the next sequential four-finger movement. After participants completed (all four) entries, the next list instruction appeared, indicating again the list number and prompting participants for the placement of the list hand (i.e. the same hand used during encoding) fingers on the response keys. Instructions for L2 recall told participants in the forget groups that they should recall all L2 items, despite the opposite instruction to forget them after L2 encoding. Then the four exclamation marks again indicated to type in all four sequences of that list in any order they came to mind, but four items had to be typed in. This procedure was repeated until all twelve items in all three lists were tested. Recall for each particular item was scored correct, if all four key presses of that item were correct (see Appendix A), whereas the input order of the items was irrelevant.

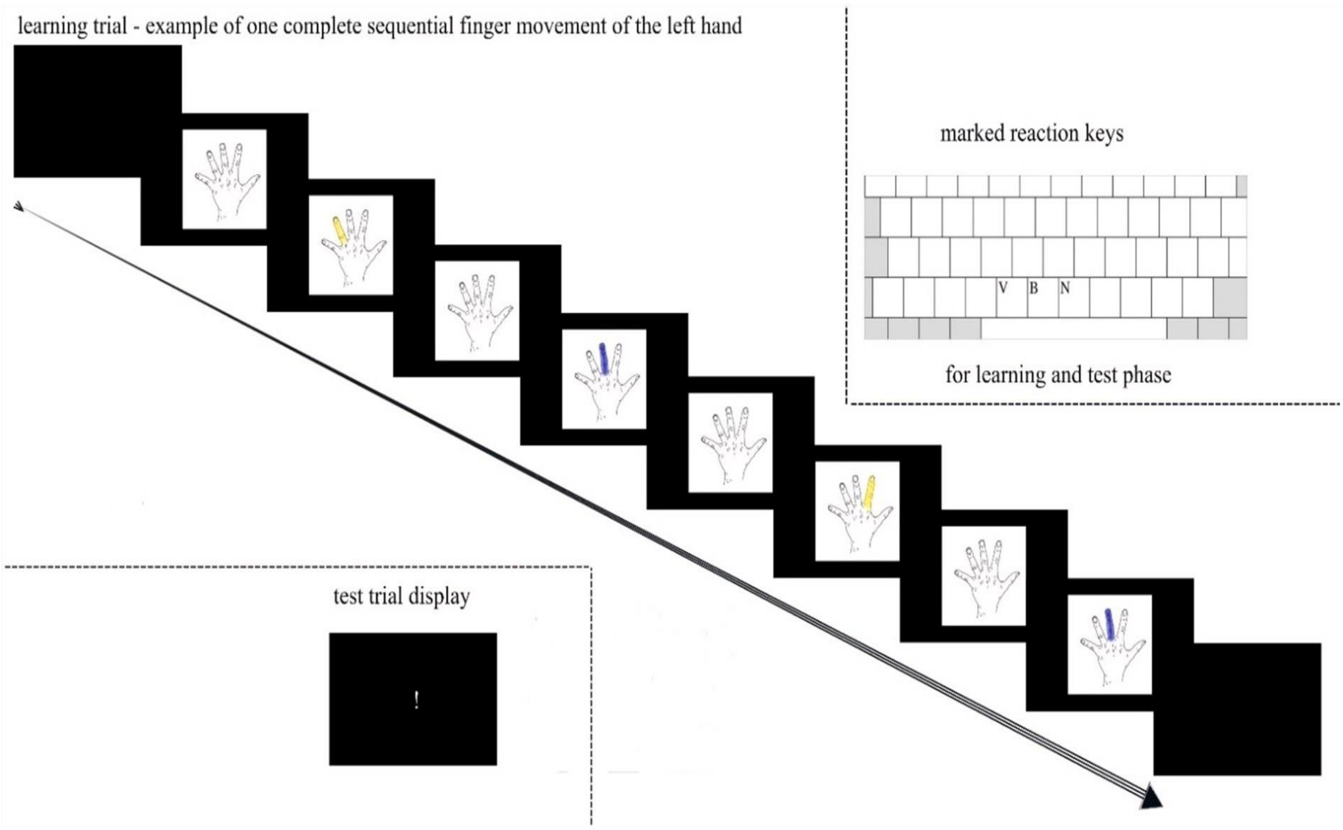

Fig. 2. The main section depicts a trial in the learning phase of L1 for item 1. It starts with a blank screen display for 3 s. Then a drawing of the left hand is given. After further 1000 ms, the first finger illuminates yellow for 200 ms, then the second finger illuminates blue for 200 ms, the third finger illuminates yellow again for 200 ms, finally the fourth finger illuminates blue for 200 ms again. Between the colored fingers, the uncolored drawing of the hand is given for 200 ms. The displayed hand subsequently disappears, and the participant is instructed to then enter the sequential finger movement just illustrated (right upper section shows the response keys for learning and test). After the sequence input, feedback for wrong key sequences was given, then the routine starts again for the next item. The left lower section shows the displayed exclamation mark in the test phase prompting for the input of a sequence.

3. Results

Recall performances for the three lists were examined in three 2 (post-L2 instruction: forget, remember) x 2 (effector switch after L2, no effector switch after L2) ANOVAs. Regarding L1, there was no significant main effect nor interaction, $F(1, 140) < 2.18$, $p > .142$, $\eta p2 < 0.015$. Thus, L1 remained unaffected by either the forget instruction or an effector switch (see Fig. 3).

Regarding L2, the main effect of post-L2 instruction was not significant, $F(1, 140) = 0.46$, $p = .498$, $\eta p2 = 0.003$, neither was the main effect of effector switch, $F(1, 140) = 2.52$, $p = .115$, $\eta p2 = 0.018$, but there was a significant interaction, $F(1, 140) = 6.21$, $p = .014$, $\eta p2 = 0.042$. Simple effects analyses showed that the forget group without effector switch after L2 (*no-switch - forget group*) recalled significantly fewer L2 items than the remember group without effector switch after L2 (*no-switch - remember group*), $F(1, 140) = 5.03$, $p = .026$, $\eta p2 = 0.035$, whereas forget (*switch - forget group*) and remember groups with effector switch (*switch - remember group*) did not differ significantly, $F(1, 140) = 1.64$, $p = .202$, $\eta p2 = 0.012$ (see Fig. 3). Thus, directed forgetting costs for L2 only occurred when the effector did not change from L2 to L3 (*no-switch group*).

Furthermore, a post hoc comparison between L1 and L2 recall in the *no-switch - forget group* showed a reliably lower recall for L2 compared to L1 recall in that group, $t(35) = 3.08$, $p = .004$, Cohen's d = 0.514. A post hoc comparison between L1 and L2 recall in the *no-switch - remember group* showed no such reliable difference between L1 and L2 recall, $t(35) = -0.43$, $p = .672$, Cohen's d = -0.071. Post hoc comparisons between L1 and L2 recall in the *switch - forget group* did not show reliable difference either, $t(35) = 0.28$ $p = .78$, Cohen's d = 0.047, nor did post hoc comparisons between L1 and L2 recall in the *switch - remember group*, t (35) = -0.34 $p = .74$, Cohen's d = -0.056. So, selective directed forgetting costs for L2 occurred, i.e. L2 recall in the *no-switch - forget* group was reliably lower than L2 recall in the *no-switch - remember group* (see Fig. 3) and *also* was reliably lower than L1 recall in the same (*forget*) group, - but *only* when the effector did not switch between L2 and L3[1] (*no-switch group*).

Regarding L3, there was no significant main effect of effector switch nor an interaction, *F*s < 1, but a significant main effect of post-L2 instruction, $F(1, 140) = 7.73$, $p = .006$, $\eta p2 = 0.052$. The forget groups recalled more L3 items than the remember groups, reflecting directed-forgetting benefits for L3.

4. Discussion

Results are in line with an inhibitory account of directed forgetting costs. An instruction to selectively forget one of two previously studied sets of motor sequences caused decreased memory accessibility of that set when it was to be enacted with the same effector as a subsequently studied set of motor sequences (*no-switch groups*), but not when the subsequently studied set involved a different effector (*switch groups*). The occurrence of

[1] Given the possibility that recall might get affected by the participants dominant hand, we conducted an ANOVA for L2 recall with the dominant hand (left, right) as an additional control factor. This control factor did not moderate the significant interaction effect between effector switch and instruction regarding L2 recall, $F(1, 136) = 1.14$, $p = .288$, $\eta p2 = 0.008$.

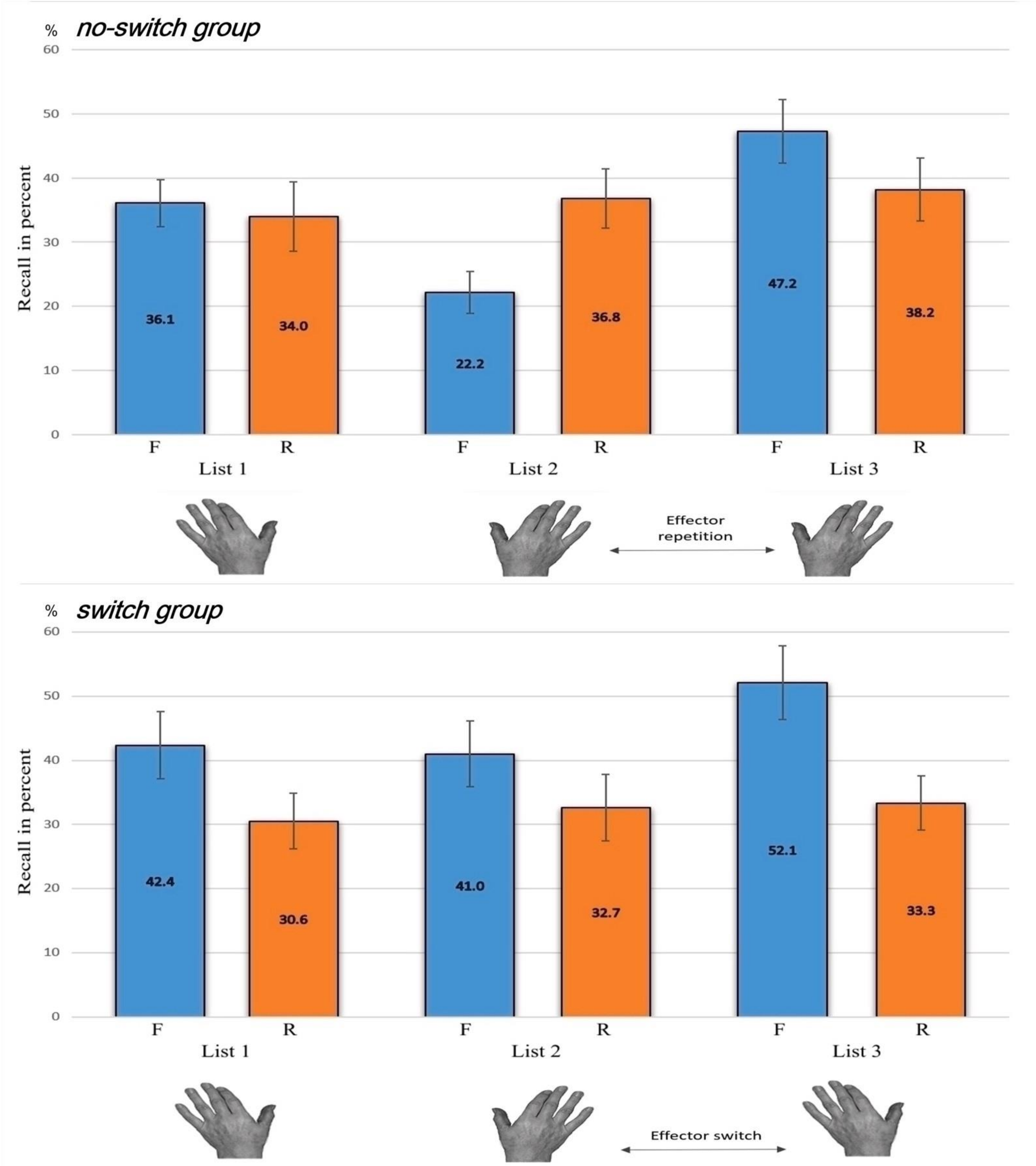

Fig. 3. Recall performance in percent for the three lists in the forget (F) and remember (R) conditions for same effector L3 as L2 (upper section – *no-switch group*) and switched effector from L2 to L3 (lower section – *switch-group*). Error bars represent ±1 S.E.M.

selective directed forgetting when the effector did not switch after L2 together with its absence when the effector did switch points to an adaptive inhibitory mechanism that serves to resolve competition between item sets as the cause of selective directed forgetting costs. Participants consecutively learned three lists of sequential finger movements. The use of different hands for L1 and L2 in all experimental groups was intended to maximize list discriminability, thus, potentially facilitating targeted inhibition. L3 also used the right hand for the lists sequence enactment (*no-switch groups*) or switched sequence enactment back to the left hand (*switch groups*). Only without effector switch after L2 (*no-switch groups*), L2 recall was reliably lower in the *forget group* than in the *remember group*, and L1 recall in the *forget group* was reliably higher than L2 recall in the *forget group* (i.e. selective directed forgetting costs occurred). Thus, our results demonstrate selective directed forgetting in motor memory for the first time. Moreover, L1 recall did not differ significantly between the *remember* and *forget* groups, which is incompatible with the assumption of a mental context change accounting for directed-forgetting costs. If the forget cue would have induced a context change, L1 recall should have been affected as well. The context-change account predicts no selectivity of costs for our LMDF variant, because both precue lists - L1 and L2 - should be equally affected by the contextual encoding-retrieval mismatch, due to the forget-cue-elicited context change. Selective costs for the second list in the absence of costs for the first list (as observed in the *no-switch groups*) cannot be explained in terms of the context-change account.

Furthermore, concerning the remaining prominent explanatory model of directed forgetting, the selective-rehearsal account (Bjork, 1970) predicts for the present experimental design, that forget-cued participants solely should rehearse the items of L1 and L3, no matter whether they were enacted with the left or the right hand. Thus, the selective-rehearsal account can explain the observed selective directed forgetting for the *no-switch group* but cannot explain its absence when the effector switched from L2 to L3. Evidence against selective rehearsal as being the cause of selective directed forgetting also comes from a recent study by Aguirre et al. (2017). In their Experiment 1, they manipulated working-memory load. Selective directed forgetting was observed under an articulatory suppression condition, suggesting "that selective rehearsal might not play a key role in producing SDF" (p.5).

Switching the effector after L2 examined whether reducing interference between L2 and L3 (by the assignment of a different hand to L3) would reduce directed forgetting costs. We assumed the change of the enacting hand to involve less or no competition at all between L2 and L3. No selective nor non-selective directed forgetting costs occurred in the *switch group*, suggesting that directed forgetting costs only occur if subsequent encoding involves a sufficient amount of competition with the precue material.

The observed absence of a cost effect when the effector changed after L2 corresponds to the idea of an adaptive inhibition mechanism, able to target a specified item set, - if this set has the potential to compete with the encoding of a novel item set. This in turn corresponds to a general inhibitory account of directed forgetting, assuming inhibition to be a (voluntary) goal-oriented executive-control mechanism resolving interference between memory contents (Anderson, 2005; Anderson & Hanslmayr, 2014; Bäuml et al., 2008; Geiselman et al., 1983; Hanslmayr et al., 2012). Inhibition should arise only if there is postcue encoding of competing (i.e. interfering) material and, correspondingly, it has been shown that no costs occur if the forget cue is followed by an insufficient amount of additional new learning material (Conway et al., 2000; Pastötter & Bäuml, 2007, 2010). This ultimately points on inhibition as being the cause of costs, resolving interference between memory contents, serving the purpose to enhance memory for to-be-remembered information (cf. Anderson, 2005). Perhaps, a modification of existing non-inhibitory accounts might be able to explain the present findings, but in a comparison of the theories presently existing in the literature our results clearly favor inhibition theory.

In the learning phase, the items of each list were executed by the same fingers of the same hand. Thus, the hand can be regarded as a cue organizing storage of the finger movements in memory. The hands have been used in a corresponding manner (i.e. for categorization of motor sequences) in previous research, in particular in studies on retrieval-induced forgetting. This memory phenomenon occurs when the selective retrieval of a subset of information causes forgetting of the non-retrieved rest of information from that set. Tempel and Frings (2013) demonstrated this effect in motor memory. After participants had studied two sets of sequential finger movements (one performed with fingers of the left hand, the other with fingers of the right hand), retrieval of only half the items of one hand induced forgetting for the other half of items of that hand. Recall in a final memory test was lower as compared to recall of items from the opposite hand. This finding together with results from subsequent studies (Tempel et al., 2016; Tempel & Frings, 2014a, 2014b, 2015, 2017) suggests that an inhibitory mechanism caused the observed retrieval-induced forgetting, resolving interference that arises during selective retrieval among the items of one set. Whereas retrieval triggered interference among items of the same hand, no interference occurred between items of the two hands, however. Thus, research on retrieval-induced forgetting shows that the hands can be used to organize storage of sequential finger movements in distinct categories.

Regarding the fact that participants in the test phase were encouraged to guess if they could not remember all four sequences of the respective list, it is possible that implicit memory also contributed to their recall performance. Even without being able to consciously recollect an item, the correct motor sequence might have been produced at a level above chance in a few instances. However, given the explicit structure of our experiment and the explicit (conscious) directed forgetting instruction, we do not believe that such implicit memory recall contributions would have been able to substantially affect the effects of directed forgetting that were of interest here. Moreover, research showed that implicit memory also can be affected by directed forgetting (e.g. MacLeod, 1989).

In everyday motor behavioral situations, this interference resolving effect of selective directed forgetting might be observed as well. Imagine, for example, the situation of practicing to serve in a tennis match. The effects of interference from previous serving habits may result in actual goal errors when one is confronted with new task demands, e.g. in form of a faster than usually reacting tennis partner. Selectively forgetting this behavioral subset of habitually targeting a certain point on the line in the opponent's field and replacing this subset with a new serving behavioral subset targeting a different than usually point may rely on this (voluntary) goal-oriented executive-control mechanism resolving interference in motor memory.

Publicly available data set

https://osf.io/89h4p/?view_only=bd24c1fd0a174ce384edc798f2 1511c8.

Declaration of competing interest

The authors have no conflicts of interests to declare.

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Appendix A

Motor sequence items of the three lists respective to the group assignment including the F(orget) vs R(emember) list cue

for the no-switch groups:

Set	Item	First finger	Second finger	Third finger	Fourth finger	Enacted by	List cue
L1	1	Ring finger	Middle finger	Index finger	Middle finger	Left hand	R
L1	2	Middle finger	Ring finger	Middle finger	Index finger	Left hand	R
L1	3	Index finger	Middle finger	Index finger	Middle finger	Left hand	R
L1	4	Index finger	Ring finger	Middle finger	Ring finger	Left hand	R
L2	5	Index finger	Ring finger	Index finger	Middle finger	Right hand	F vs R
L2	6	Middle finger	Index finger	Middle finger	Index finger	Right hand	F vs R
L2	7	Middle finger	Ring finger	Index finger	Ring finger	Right hand	F vs R
L2	8	Ring finger	Index finger	Middle finger	Ring finger	Right hand	F vs R
L3	9	Index finger	Middle finger	Ring finger	Index finger	Right hand	R
L3	10	Index finger	Ring finger	Index finger	Ring finger	Right hand	R
L3	11	Middle finger	Ring finger	Index finger	Middle finger	Right hand	R
L3	12	Ring finger	Middle finger	Ring finger	Index finger	Right hand	R

and the switch groups:

Set	Item	First finger	Second finger	Third finger	Fourth finger	Enacted by	List cue
L1	1	Ring finger	Middle finger	Index finger	Middle finger	Left hand	R
L1	2	Middle finger	Ring finger	Middle finger	Index finger	Left hand	R
L1	3	Index finger	Middle finger	Index finger	Middle finger	Left hand	R
L1	4	Index finger	Ring finger	Middle finger	Ring finger	Left hand	R
L2	5	Index finger	Ring finger	Index finger	Middle finger	Right hand	F vs R
L2	6	Middle finger	Index finger	Middle finger	Index finger	Right hand	F vs R
L2	7	Middle finger	Ring finger	Index finger	Ring finger	Right hand	F vs R
L2	8	Ring finger	Index finger	Middle finger	Ring finger	Right hand	F vs R
L3	9	Ring finger	Middle finger	Index finger	Ring finger	Left hand	R
L3	10	Ring finger	Index finger	Ring finger	Index finger	Left hand	R
L3	11	Middle finger	Index finger	Ring finger	Middle finger	Left hand	R
L3	12	Index finger	Middle finger	Index finger	Ring finger	Left hand	R

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2 References

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Aguirre, C., Gómez-Ariza, C. J., Bajo, M. T., Andrés, P., & Mazzoni, G. (2014). Selective voluntary forgetting in young and older adults. *Psychology and Aging, 29(1)*, 128–139. 10.1037/a0035598

Aguirre, C., Gómez-Ariza, C.J., Andrés, P., Mazzoni, G., & Bajo, M.T. (2017). Exploring Mechanisms of Selective Directed Forgetting. *Frontiers in Psychology, 8:316*, 1-15. https://doi.org/10.3389/fpsyg.2017.00316

Aguirre, C., Gómez-Ariza, C. J., & Bajo, M. T. (2020). Selective directed forgetting: Eliminating output order and demand characteristics explanations. *Quarterly Journal of Experimental Psychology*. https://doi.org/10.1177/1747021820915100

Anderson, M. C. (2005). The role of inhibitory control in forgetting unwanted memories: A consideration of three methods. In C. MacLeod and B. Uttl (Eds.), *Dynamic Cognitive Processes* (pp. 159–190). Tokyo: Springer-Verlag.

Anderson, M. C., & Hanslmayr, S. (2014). Neural mechanisms of motivated forgetting. *Trends in Cognitive Science, 18*, 279–292. https://doi.org/10.1016/j.tics.2014.03.002

Bäuml, K.-H., Hanslmayr, S., Pastötter, B., & Klimesch, W. (2008). Oscillatory correlates of intentional updating in episodic memory. *Neuroimage, 41,* 596–604. https://doi.org/10.1016/j.neuroimage.2008.02.053

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Verbal Learning and Verbal Behavior, 9,* 255–268. https://doi.org/10.1016/S0022-5371(70)80059-7

Bjorklund, D. F., & Harnishfeger, K. K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review, 10,* 48-71. https://doi.org/10.1016/0273-2297(90)90004-N

Burwitz, L. (1974). Proactive interference and directed forgetting in short-term motor memory. *Journal of Experimental Psychology, 102*(5), 799–805. https://doi.org/10.1037/h0036361

Conway, M. A., Harries, K., Noyes, J., Racsma`ny, M., & Frankish, C. R. (2000). The disruption and dissolution of directed forgetting: Inhibitory control of memory. *Journal of Memory and Language, 43,* 409–430. https://doi.org/10.1006/jmla.2000.2706

Delaney, P. F., Nghiem, K., & Waldum, E. R. (2009). The selective directed forgetting effect: Can people forget only part of a text? *Quarterly Journal of Experimental Psychology, 62,* 1542-1550. https://doi.org/10.1080/17470210902770049

Geiselman, R. E., Bjork, R. A., & Fishman, D. (1983). Disrupted retrieval in directed forgetting: A link with posthypnotic amnesia. *Journal of Experimental Psychology: General, 112(1),* 58–72. https://doi.org/10.1037/0096-3445.112.1.58

Gómez-Ariza, C. J., Iglesias-Parro, S., Garcia-Lopez, L. J., Díaz-Castela, M. M., Espinosa-Fernández, L., & Muela, J. A. (2013). Selective intentional forgetting in adolescents with social anxiety disorder. *Psychiatry Research, 208(2)*, 151–155. https://doi.org/10.1016/j.psychres.2012.09.027

Hanslmayr, S., Volberg, G., Wimber, M., Oehler, N., Staudigl, T., Hartmann, T., et al. (2012). Prefrontally driven down-regulation of neural synchrony mediates goal-directed forgetting. *Journal of Neuroscience, 32,* 14742–14751. https://doi.org/10.1523/JNEUROSCI.1777-12.2012

Irtel, H. (2007). *PXLab: The Psychological Experiments Laboratory* [online]. Version 2.1.11. Mannheim (Germany): University of Mannheim. Available from http://www.pxlab.de

Kliegl, O., Pastötter, B., & Bäuml, K.-H. T. (2013). List-method directed forgetting can be selective: Evidence from the 3-list and the 2-list tasks. *Memory & Cognition, 41,* 452–464. https://doi.org/10.3758/s13421-012-0264-7

Kliegl, O., Wallner, L., & Bäuml, K.-H. T. (2018). Selective directed forgetting in children. *Journal of Experimental Child Psychology, 167*, 433-440. https://doi.org/10.1016/j.jecp.2017.11.002

MacLeod, C. (1989). Directed forgetting affects both direct and indirect tests of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15(1), 13–21.* https://psycnet.apa.org/doi/10.1037/0278-7393.15.1.13

MacLeod, C. (1998). Directed forgetting. In J.M. Golding and C. MacLeod (Eds.), *Intentional Forgetting: Interdisciplinary Approaches* (pp. 1-57). Hillsdale, NJ: Erlbaum.

Pastötter, B., & Bäuml, K.-H. (2007). The crucial role of postcue encoding in directed forgetting and context-dependent forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33(5),* 977– 982. https://doi.org/10.1037/0278-7393.33.5.977

Pastötter, B., & Bäuml, K.-H. (2010). Amount of postcue encoding predicts amount of directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36(1),* 54-65. http://dx.doi.org/10.1037/a0017406

Pastötter, B., Kliegl, O., & Bäuml, K.-H. T. (2012). List-method directed forgetting: The forget cue improves both encoding and retrieval of postcue information. *Memory & Cognition, 40,* 861–873. https://doi.org/10.3758/s13421-012-0206-4

Sahakyan, L. (2004). Destructive effects of "forget" instructions. *Psychonomic Bulletin & Review, 11,* 555–559. https://doi.org/10.3758/BF03196610

Sahakyan, L., & Delaney, P. F. (2003). Can encoding differences explain the benefits of directed forgetting in the list method paradigm? *Journal of Memory and Language, 48,* 195–206. https://doi.org/10.1016/S0749-596X(02)00524-7

Sahakyan, L., & Foster, N. L. (2009). Intentional forgetting of actions: Comparison of list-method and item-method directed forgetting. *Journal of Memory and Language, 61(1)*, 134-152. https://doi.org/10.1016/j.jml.2009.02.006

Sahakyan, L., & Kelley, C. M. (2002). A contextual change account of the directed forgetting effect. Journal of Experimental Psychology: *Learning, Memory, and Cognition, 28(6),* 1064–1072. https://doi.org/10.1037/0278-7393.28.6.1064

Storm, B. C., Koppel, R. H., & Wilson, B. M. (2013). Selective cues to forget can fail to cause forgetting. *The Quarterly Journal of Experimental Psychology, 66(1)*, 29–36. https://doi.org/10.1080/17470218.2012.753923

Tempel, T., Aslan, A. & Frings, C. (2016). Competition dependence of retrieval induced forgetting in motor memory. *Memory & Cognition, 44(4),* 671-680. http://dx.doi.org/10.3758/s13421-015-0578-3

Tempel, T., & Frings, C. (2013). Resolving interference between body movements: Retrieval-induced forgetting of motor sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39,* 1152–1161. http://dx.doi.org/10.1037/a0030336

Tempel, T., & Frings, C. (2014a). Forgetting motor programmes: Retrieval dynamics in procedural memory. *Memory, 22,* 1116–1125. https://doi.org/10.1080/09658211.2013.871293

Tempel, T., & Frings, C. (2014b). Interference within hands: Retrievalinduced forgetting of left and right hand movements. *Acta Psychologica, 148,* 1–5. https://doi.org/10.1016/j.actpsy.2014. 01.003

Tempel, T. & Frings, C. (2015). Categorization by movement direction: Retrieval induced forgetting of motor sequences grouped by motion features. *The Quarterly Journal of Experimental Psychology, 68,* 473-486. https://doi.org/10.1080/17470218.2014.945098

Tempel, T., & Frings, C. (2016). Directed forgetting benefits motor sequence encoding. *Memory & Cognition, 44,* 413–419. http://dx.doi.org/10.1080/09658211.2015.1059858

Tempel, T., & Frings, C. (2017). Retrieval-induced forgetting is retrieval-modality specific: Evidence from motor memory. *Cognition, 162 (2017),* 143–152. http://dx.doi.org/10.1016/j.cognition.2017.02.005

4.3. Artikel 3: Suppression-induced forgetting of motor sequences

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Suppression-induced forgetting of motor sequences

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A B S T R A C T

Two experiments examined the effects of deliberately suppressing retrieval of motor sequences on their later recall, in the *think/no-think paradigm* (Anderson & Green, 2001). After several motor sequences had been associated with individual cues through repeated practice cycles, a subset of these sequences was retrieved in response to their respective cues (*think* trials), whereas other sequences were suppressed. In such *no-think* trials, cues were shown but participants were instructed to withhold the associated motor response and to suppress its recollection. We found that suppressing retrieval impaired later memory performance for the suppressed sequences in comparison to items that were not cued at all after their initial training (*baseline* sequences). Suppression impaired later sequence recall and sequence speed although in different ways depending on the training level: with higher initial training of sequences (Experiment 1), suppression impaired reaction time, but not recall accuracy; with lower initial training (Experiment 2), suppression reduced recall accuracy. Reaction time analyses revealed a consistent slowing of movement execution for suppressed sequences. These findings show that inhibitory control processes engaged during retrieval suppression can influence memory representations of motor actions, by not only reducing their accessibility but also by affecting their execution, once retrieved.

Keywords:

Suppression-induced forgetting, Inhibition, Executive control, Forgetting, Motor sequences

Imagine a soccer player shooting at the goal. Moments before he hits the ball a defender blocks the aimed direction. The player now can stop this already initialized motor sequence and replace it with a new motor sequence in a different shot angle or by stopping the shot. This ability to control overt behavior is based on executive control processes. Inhibitory processes are thought of implementing a response override function, thereby enabling adaptive control over motor actions. Anderson and Green (2001) demonstrated that inhibitory control processes may also contribute to preventing unwanted memories from entering consciousness. They showed that consistently stopping retrieval of unwanted memories made subsequent recall of these memories more difficult.

The *think/no-think* task, an adaptation of the go/no-go paradigm (used to measure the capability to stop a prepotent motor response), examines the consequences of voluntarily stopping memory retrieval. After studying weakly related word-pairs (e.g., flag – sword), participants are trained to recall and say the associated word as fast as possible when the first word is presented. After training, the *think/no-think* task begins. For *think* trials the task is identical to training. For *no-think* trials, however, participants are instructed to not only avoid saying the response word when the cue is presented, but also to stop the associated memory from entering awareness at all. In a final recall test for all items, participants typically recall fewer *no-think* items compared to *baseline* items, which were studied initially, but which did not appear in the *think/no-think* phase. Impaired memory for *no-think* items, known as suppression-induced forgetting (SIF), has been argued to arise because suppressing retrieval entails inhibition of the target's memory representation (Anderson & Green, 2001; see Anderson & Hulbert, 2021, Marsh & Anderson, n.d. for reviews).

Although initially studied in verbal episodic memory tasks, SIF is not restricted to verbal material or even to episodic memory. Indeed, SIF has been demonstrated on a variety of indirect memory tests, including perceptual identification (Gagnepain, Henson, & Anderson, 2014; Kim & Yi, 2013; Mary et al., 2020) or conceptual priming (Hertel, Maydon, Ogilvie, & Mor, 2018; Taubenfeld, Anderson, & Levy, 2019; Wang, Luppi, Fawcett, & Anderson, 2019). According to the reinstatement principle (Gagnepain, Hulbert, & Anderson, 2017; Hu, Bergstrom, Gagnepain, & Anderson, 2017), disruptions to implicit memory for suppressed content should arise for the content that gets reactivated by cues on a given trial, including sensory, semantic, and emotional aspects of an experience. Consistent with this principle, suppressing retrieval down-regulates hippocampal activity together with fusiform cortex, parahippocampal cortex, or the amygdala, depending on whether objects, scenes, or emotional content are suppressed (see, e.g., Gagnepain et al., 2017; Gagnepain et al., 2014). If retrieval suppression can be flexibly targeted at regions of the neocortex representing specific types of content, suppressing retrieval of motor actions might affect motor cortex. Suppression of motor cortical regions should disrupt motoric features representing movement execution of practiced responses, potentially revealing the existence of *motor SIF*.

If motor SIF occurs, retrieval suppression should inhibit movement representations when reminders of to-be-suppressed items elicit motor sequences associated to them. Several lines of work support this hypothesized extension of SIF to motor actions. First, inhibition in memory shares functional similarities with motor-response inhibition, both occurring when responses are voluntarily stopped in response to a cue (Anderson & Green, 2001). At the level of neural systems, evidence suggests that retrieval and action stopping activate a common domain-general stopping mechanism (Anderson & Hanslmayr, 2014; Apšvalka, Ferreira, Schmitz, Rowe, & Anderson, 2022; Castiglione, Wagner, Anderson, & Aron, 2019; Depue, Orr, Smolker, Naaz, & Banich, 2016; Guo, Schmitz, Mur, Ferreira, & Anderson, 2018) that can be targeted at either mnemonic or motor representations. These functional and anatomical similarities suggest that SIF might not be restricted to words or images typically used as items, but also may extend to memory representations of motor sequences. This possibility is further supported by evidence that other memory inhibition phenomena have parallels in motor memory. For example, studies on retrieval-induced forgetting by Tempel and Frings (2013, 2014, 2017) suggest that an inhibitory mechanism resolves interference between motor programs that arises when a subset of motor responses associated with a cue needs to be retrieved. Schmidt, Frings, and Tempel (2021) also recently showed that a set of studied motor sequences can be affected by selective directed forgetting if that set could interfere with other to-be-retained motor sequences. Such findings suggest that inhibitory processes that impair episodic memory can induce forgetting of motor memories as well, whilst also documenting motor-specific properties of these inhibition effects.

To test for the existence of motor SIF, we designed a motor sequence variant of the *think/no-think* paradigm. In this adapted task, participants were trained to execute sequences of finger movements whenever they were prompted with the sequence's paired letter stimulus as a cue. After being trained on 12 such letter-sequence pairings, participants entered the *think/no-think* task. In this task, participants performed trials on which they received the letter cue from one of the learned pairs, presented in either a green or a red font. When the cue appeared in green (the *think* task), participants were asked to recall and perform the associated motor sequence as quickly as possible. When the cue appeared in red, however, (the *no-think task*), participants were asked to not only not execute the paired sequence, but also to fully suppress the sequence from awareness, preventing it from being retrieved for the entire ten second duration of the trial. Each item was either suppressed or retrieved twelve times during the *think/no-think* phase. A final recall test then presented participants with each letter cue and asked them to recall and execute the paired sequence as quickly as possible. If suppressing retrieval inhibits the accompanying motor memory, then the accessibility of *no-think* sequences should decline, compared to that of *baseline* sequences that were trained, but that did not undergo suppression in the interim. If memorized finger sequences exhibit *motor SIF*, it would suggest that common inhibitory dynamics apply across episodic and motor memory representations.

1. Experiment 1

Participants first studied and practiced executing 12 three-finger sequences as responses to letters. In the subsequent *think/no-think* task, they were cued on *think* trials to recall the relevant sequence and to execute it as fast as possible. For *no-think* items, their task was not only to stop the motor action, but also to suppress any thoughts about the finger order of the cue-related sequence—to stop motor retrieval. After receiving these instructions, the *think/no-think* trials began. *Think/no- think* items were randomly intermixed in each of four blocks. A final cued recall test assessed memory for all items. We expected that retrieval suppression would impair the accessibility of *no-think* items, compared to *baseline* items. Such impairment may be reflected in reduced sequence recall accuracy, as well as slowed sequence retrieval or execution. The dual processor model by Abrahamse, Ruitenberg, De Kleine, and Verwey (2013) assumes that responding with a trained motor sequence to a cue stimulus involves a cognitive and a motor processor. The cognitive processor translates the stimulus into the associated response and loads the motor buffer. Sequence initiation reflects these steps, whereas subsequent sequence execution primarily reflects the motor processor that is assumed to execute loaded movements in an autonomous manner. Therefore, we not only analyzed total reaction times, but also response times for the first keypress (indicating sequence initiation) and for the remaining keypresses (indicating sequence execution) separately.

1.1. Method

1.1.1. Participants

Sixty students at the Ludwigsburg University of Education (mean age = 23.4) participated in the experiment and were paid 15 Euro each.

1.1.2. Design

Item type was manipulated within participants on three levels: *think* (T), *no-think* (NT), and *baseline* (B). Each item type comprised three sequences. In addition, three filler items were employed for training purposes only. The dependent variables measured were the number of fully correctly recalled sequences, the number of correct first keypresses, the number of trials with correct second and third keypress, reaction time to begin recalling a sequence (first key press), and speed of sequence execution (second and third key press).

1.1.3. Material

The items consisted of twelve sequential three-finger movements of the index-, middle-, ring finger and pinkie of the right hand. These items had to be enacted by pressing the keys V, B, N, and M. At the beginning of the sequence, we presented a black drawing of the right hand on a white background in the center of the screen for 700 milliseconds (ms). We then cued each sequence by a consonant displayed for another 800 ms above the hand. Three different fingers subsequently illuminated for 200 ms each, animating the to-be-enacted sequence. The index and ring finger illuminated in yellow, the middle finger and pinkie in blue. After we presented the sequence, the hand and letter cue disappeared and we instructed participants to press the corresponding keys with their right hand, remembering both the sequence and the associated letter. Each finger rested on its respective key during the whole procedure. Wrong keypress orders were indicated by a 800 ms feedback message "falsch!" (English: "wrong!"). Correctly entered sequences were followed by 800 ms blank screen instead. After a further 700 ms blank screen the next trial started (see Fig. 1).

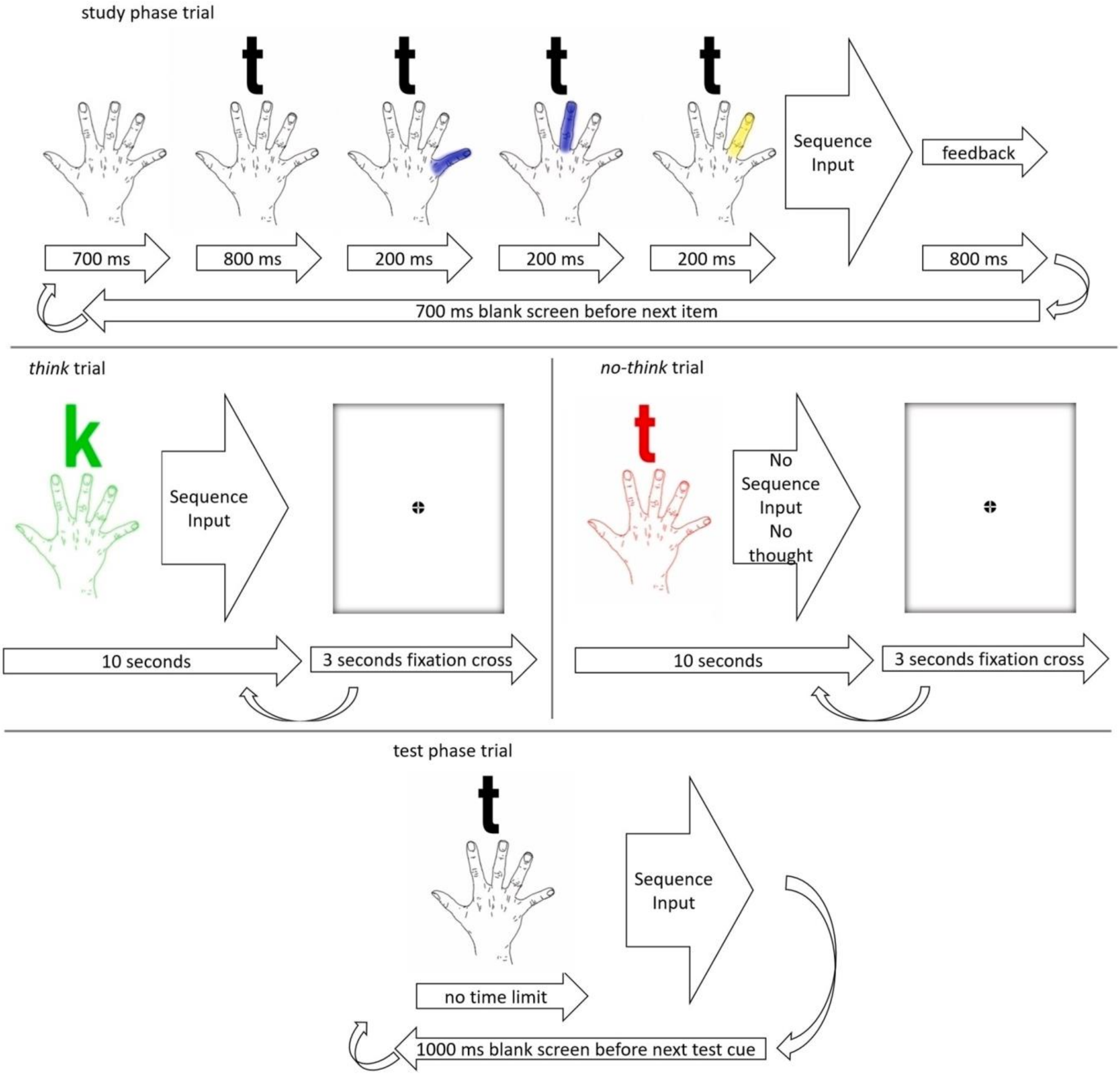

Fig. 1. Schematic diagram for an example trial of the study, *think/no-think* and the final test phases in both experiments. In Experiment 1, the criterion test trial additionally encompassed corrective feedback. A typical final test trial in both experiments is displayed.

1.2. Procedure

The experiment was conducted online. The experimental routine was implemented with the software PsychoPy in Version 3.2 (Peirce, Gray, Simpson, et al., 2019) and uploaded to the pavlovia.org servers. Participants received a hyperlink to access the experiment on pavlovia.org and to run it then via their own internet browser. Simultaneously, the experimenter was connected in a video call via Cisco Webex Meetings. The experiment consisted of four parts: Study trials, training, *think/no-think* trials, and final cued recall. Participants first joined a Cisco Webex session with the experimenter and opened a link to the study trials in their browser. After initial instructions, they received a short example of study trials with filler items to familiarize them with the task. Then they received a test for the three filler items. After the experimenter had ensured the comprehension of the procedure, study of the experimental items started. The participants` fingers of their right hand rested on the keys V (index finger), B (middle finger), N (ring finger), and M (pinkie) during all study trials. After seven study cycles of the twelve items, the first test was given. Participants were cued with a letter plus the hand drawing and instructed to perform the corresponding sequence. Wrong input was followed by an error message and an immediate presentation of the correct sequence that subsequently had to be performed again. Feedback about the percentage of correctly entered sequences was given after testing all 12 items. If the participant entered nine or more sequences correctly (≥ 75%) the study trials ended. If not, the participant received two further study cycles for the 12 items, followed by a test again. This repeated until the participant reached the criterion or a maximum of 15 study cycles.

Participants then opened a second link to enter the *think/no-think* phase. Instructions explained the two different types of mental andmotor responses to *think* or *no-think* items. For items cued in green (*think* items), the task was to recall the sequence belonging to the presented letter and execute it via the keys V, B, N, and M. In contrast, items cued in red (*no-think* items) were not only not to be executed, but also were to be excluded from entering conscious awareness at all. The experimenter ensured the task comprehension verbally. Then two blocks of *think* or *no-think* training with the filler items began. After each block, face-to-face feedback ensured the participants' correct task performance; a task-related questionnaire was given about each of the key task elements and directive feedback supplied. The subsequent *think/no-think* trials comprised four blocks intermixing *think* and *no-think* trials, each with a short break before the next one. After two blocks, the task-related questionnaire was administered again, and feedback provided. The final *think/no-think* block was followed by an immediate cued recall test. Each trial presented the same drawing of the hand as before together with a letter cue, both in black. Participants were instructed to execute the corresponding motor sequence via the same keys as used previously (V, B, N and M). After three key presses, a blank screen appeared for 1000 ms before the next trial started. Filler items were cued first, then all nine experimental items in a random order. We divided the experimental items in groups of three that were assigned to each item type once (T, NT or B), resulting in three counterbalancing variations that were randomly assigned to participants.

1.3. Results

To assess the impact of retrieval suppression on sequence memory, we assessed the accuracy of sequence recall and reaction times. Regarding reaction time, only those items were analyzed that had been correctly recalled in the criterion test and in the test phase. Reaction times for the first keypress (initiation time) and reaction times for the second and third keypress of a sequence (execution time) were analyzed. Regarding accuracy, we first analyzed the number of correctly recalled sequences. In addition, we compared the number of trials with a correct first keypress to the number of trials with correct second and keypresses (irrespective of the correctness of the first key). Separate repeated-measures ANOVAs for accuracy and response times examined differences between the three item types, supplemented by planned comparisons of B and NT items as well as B and T items.

A one-factor (item type: NT, B, T) ANOVA examined the number of correct sequences. The main effect was not significant, $F < 1$, neither were pairwise comparisons of B and NT items ($p = .306$) or B and T items ($p = .397$). In a 2 (first keypress, second and third keypresses) x 3 (item type: NT, B, T) ANOVA, there was only a significant main effect indi-cating that the number of correct first keypresses was higher than the number of correct second and third keypresses, $F(1, 59) = 83.84$, $p < .001$, $\eta p2 = 0.59$. The main effect of item type was not significant, $F < 1$, neither was the interaction, $F(2, 118) = 1.49$, $p = .251$.

In contrast to performance on accuracy, the *think/no-think* manipulation had robust effects on reaction time. A 2 (initiation time, execution time) x 3 (item type: NT, B, T) ANOVA examined reaction times. The main effect of item type was significant, $F(2, 84) = 21.48$, $p < .001$, $\eta p2 = 0.34$, as was the main effect indicating overall longer initiation than execution time, $F(1, 42) = 138.47$, $p < .001$, $\eta p2 = 0.77$. The interaction was significant as well, $F(2,84) = 13.58$, $p < .001$, $\eta p2 = 0.24$ (see Fig. 2). Simple effects analyses showed that NT items were initiated significantly more slowly than B items ($p = .002$) that were initiated significantly more slowly than T items ($p < .001$). In addition, the execution time of NT items was significantly longer than the execution time of T items ($p = .002$), whereas the execution time of B items fell in between but differed only marginally from NT items ($p = .058$) and T items ($p = .071$).

1.4. Discussion

Our *think/no-think* manipulation influenced later retention of sequences on the final test. Whereas the initiation of T items was faster than the initiation of B items, the initiation of NT items was slower than the initiation of B items. There was also an effect of item type on execution times. Although only the difference between T and NT items was significant, NT items showed a trend to be slower than B items. Thus, it is unclear whether the execution of T items was facilitated or the execution of NT items suffered or both.

The dual processor model (Abrahamse et al., 2013) assumes that a cognitive and a motor processor are responsible for skilled movement execution. The cognitive processor translates an externally presented stimulus (the letter) into the associated response and may also load

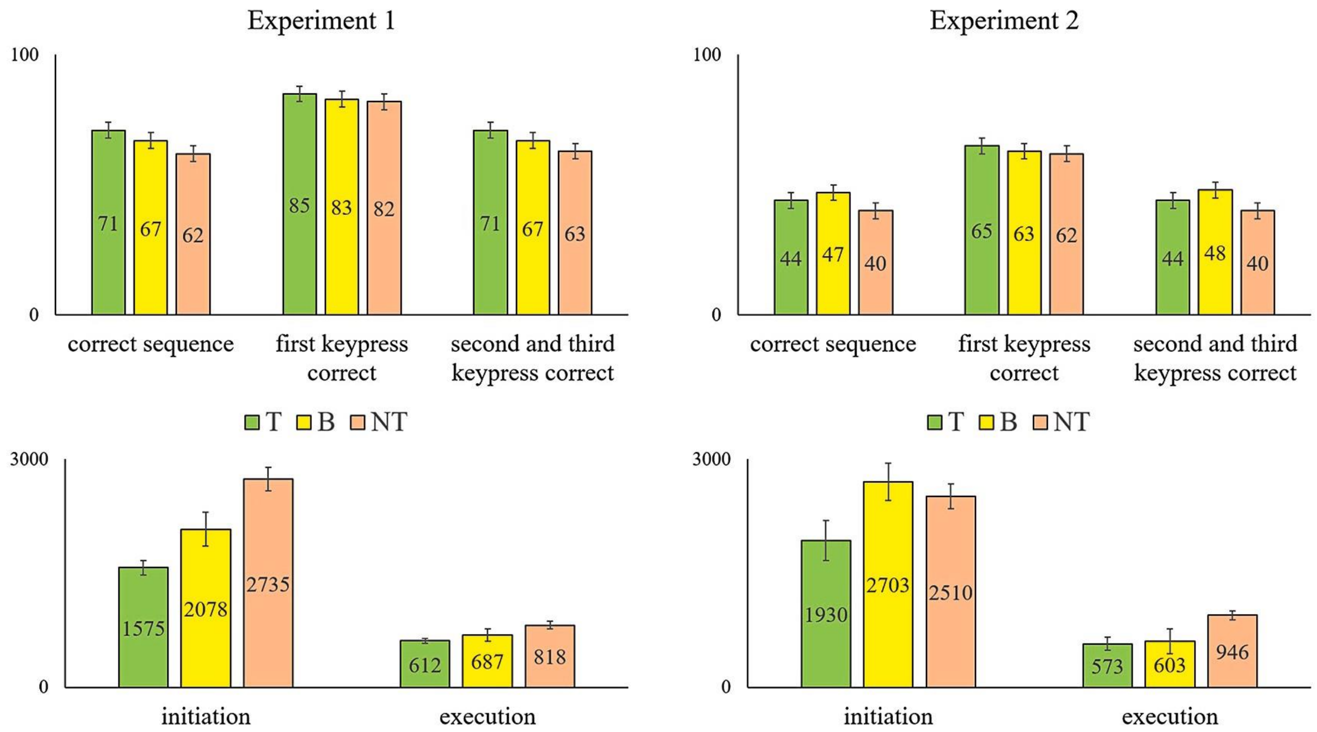

Fig. 2. The upper section of the diagram shows accuracy in percent for the three item types *think* (T), *baseline* (B), and *no think* (NT). The lower section shows response times in milliseconds for initiation and execution of correctly recalled sequences. Error bars represent ±1 S.E.M.

the motor buffer with a limited amount of these response elements. This is thought of as happening between stimulus onset and the first keypress. The first keypress, which is typically much slower than those that follow, initiates the sequence, and is assumed to encompass both item selection and execution preparation (i.e., loading of the motor buffer). After motor buffer loading, the motor processor is assumed to execute loaded movements in an autonomous manner. Based on this analysis, reaction times for the second and third keypresses of the present sequence items would primarily reflect movement execution processes, whereas the first keypress would reflect the accessibility of the motor sequence repre-sentation in memory. Analysis for these sequence elements for the T and B comparison thus showed more rapid access to the sequence for T items, relative to B items, and a marginally significant slowing of NT items, relative to B items.

In contrast to reaction times, no reliable effects of the item-type manipulation occurred in recall accuracy. Thus, contrary to our predictions, the ability to correctly remember the motor sequence that went with a cue was not reliably affected by either repeated retrieval or repeated suppression. On the one hand, this could reflect an intrinsic difference in the susceptibility of motor representations to forgetting effects induced by inhibition, rendering them qualitatively different from episodic representations that do show such forgetting effects. On the other hand, the presence of reaction time slowing for initiating suppressed sequences suggests otherwise. One way of reconciling these discrepant observations may lie in training given to motor sequences. We used a high criterion level of training, requiring at least 75% of the sequences to be learned within a maximum of fifteen learning cycles and five criterion tests. This level of training may have rendered motor sequences more resilient to disruption, with the impact of suppression then primarily expressed in response speed. Thus, it is possible that we failed to observe forgetting for NT items (or enhancement for T items), because our items overall were extremely well trained. To address this possibility, we conducted Experiment 2, in which we altered the procedures of Experiment 1 to reduce overall performance levels.

2. Experiment 2

2.1. Method

2.1.1. Participants

Sixty students (mean age = 22.6) at the Ludwigsburg University of Education participated in the experiment. All students were paid ten Euros each for their participation.

2.1.2. Design

The design was identical to Experiment 1.

2.1.3. Material

The experiment was conducted using PCs with standard German QWERTZ keyboards in a lab at the Ludwigsburg University of Education. The software PsychoPy in version 1.90.1 (Peirce et al., 2019) served for running the experiment. The sequence items were identical to Experiment 1, but we added four more sequential three-finger movements of the index-, middle-, ring finger and pinkie of the right hand, yielding a total of 16.

2.2. Procedure

The experiment consisted of the same four parts as did Experiment 1 (study trials, training, *think/no-think* trials, and final cued recall). Participation in Experiment 2 was not online. After initial instructions and a short example trial for the learning and subsequent (criterion) test trials, participants received five trials of learning for the sixteen items in a random order. Then the first criterion test began. The error message for incorrectly entered sequences was used here again, but the correct sequence was not represented once again after these execution errors. When participants reached a criterion of at least 50% correctly recalled sequences, learning was terminated. Otherwise, participants received another learning trial followed by another test. This repeated until the criterion was reached, or ten learning trials took place. The remainder of the procedure was identical to Experiment 1.

2.3. Results

The same dependent variables were analyzed in repeated-measures ANOVAs and planned comparisons, additionally including the experimenter as a control variable. Whereas the same experimenter had run the experiment with all participants in Experiment 1, five experimenters took part in Experiment 2. We included this control factor in analyses to validate that experimenter effects did not occur.

Unlike in Experiment 1, significant effects of the *think/no-think* manipulation occurred in motor sequence recall accuracy. Whereas there was only a marginal main effect of item type in a one-factor ANOVA examining the number of correct sequences (item type: NT, B, T), $F(2,110) = 1.97$, $p = .087$, $\eta p2 = 0.04$, pairwise comparisons showed that significantly fewer NT items than B items were recalled ($p = .035$), whereas the number of recalled T items did not differ from B items ($p = .703$). In addition, there was a significant interaction in a 2 (first keypress, second and third keypresses) x 3 (item type: NT, B, T) ANOVA, $F(2, 110) = 3.84$, $p = .024$, $\eta p2 = 0.07$. The number of correct first keypresses did not differ significantly between NT and B items ($p = .913$) or between T and B items ($p = .730$), whereas the number of correct second and third keypresses was significantly lower for NT than B items ($p = .034$) but did not differ significantly between T and B items ($p = .668$).

Regarding reaction times, a significant main effect again indicated longer initiation than execution time, $F(1,32) = 78.65$, $p < .001$, $\eta p2 = 0.71$. The main effect of item type was significant as well, $F(2, 64) = 3.39$, $p = .040$, $\eta p2 = 0.10$, whereas the interaction was not significant, $F(2, 64) = 2.35$, $p = .104$. Reaction times for T items were significantly shorter than reaction times for B items ($p = .023$), whereas reaction times for NT items did not differ significantly from reaction times for B items ($p = .735$).

2.4. Cross-experiment analyses

Additional analyses collapsed across data from both experiments to examine whether the observed suppression effects were significantly moderated by experiment. Interpretation of the results from these analyses, however, must take into account the differences between experiments. The number of items and the amount of training differed. Experiment 1 was conducted online, Experiment 2 in a lab.

A significant interaction indicated that item type affected the first keypress differently than the second and third keypresses, $F(1, 228) = 5.54$, $p = .004$, $\eta p2 = 0.05$. The three-way interaction with experiment was not significant, $F(1, 228) = 1.07$, $p = .342$. The number of correct first keypresses did not differ significantly between NT and B items ($p = .872$) or between T and B items ($p = .881$), whereas the number of correct second and third keypresses was significantly lower for NT than B items ($p = .015$) but did not differ significantly between T and B items ($p = .714$).

Regarding reactions times, a significant interaction indicated that item type affected initiation and execution differently, $F(2, 148) = 4.48$, $p = .013$, $\eta p2 = 0.06$. This interaction was not moderated by experiment, $F < 1$. Simple effects analyses showed that T items were initiated significantly more quickly than B items ($p = .002$), whereas B items were not initiated significantly more quickly than NT items ($p = .857$). In contrast, NT items were executed significantly more slowly than B items ($p = .006$), whereas B items were not executed significantly more slowly than T items ($p = .591$).

2.5. Discussion

Procedural changes and a larger number of sequences to learn made learning harder, just as intended. Overall recall accuracy declined substantially as compared to Experiment 1. As predicted, these measures led to SIF in motor recall accuracy, although without an accompanying effect in the speed of movement initiation. Cross-experimental analyses additionally suggested that suppression affected execution speed as well but not initiation speed, whereas the initiation of T items was facilitated. Thus, reaction times may reflect that sequence representations of the NT items suffered because of suppression. Despite the training of T items during *think* trials, the accuracy for T items was not higher as compared to B items. In fact, accuracy for B items was slightly higher than for T items. However, this difference was not significant and we, therefore, hesitate to interpret it as indicating a disadvantage. It is safe to say that no facilitation of T items regarding accuracy was observed. The lack of a facilitation of T items is not unusual in studies with the *think/no-think* paradigm, however (e.g., Catarino, Küpper, Werner-Seidler, Dalgleish, & Anderson, 2015; Küpper, Benoit, Dalgleish, & Anderson, 2014; Levy & Anderson, 2012; Schmitz, Correia, Ferreira, Prescott, & Anderson, 2017). Yet, there was a facilitation of item initiation. It might be worthwhile considering response speed as a dependent variable in studies with more common material, such as, words or images, as well.

3. General Discussion

In two experiments we observed evidence of SIF in memory for motor sequences. In Experiment 1, motor SIF did not show up on our accuracy measure but did occur on measures of the speed of sequence initiation and execution. T items were recalled and executed more quickly than were baseline items, which in turn were recalled more quickly than were NT items. Experiment 1 also revealed a trend towards slower execution speed for NT compared to B items. In Experiment 2, we reduced the training given to pairs and increased the amount to be learned to make it more likely to observe a SIF effect in recall accuracy, and indeed found motor SIF on our recall accuracy measure. A comparison of the number of correct first keypresses with the number of correct second and third keypresses suggests that memory for sequences as entities suffered because of suppression. It was not the first element that was affected but the full sequence. This pattern of results suggests that it was not the association with the letter stimulus that was weakened but representations of the sequences became inhibited. Moreover, the sequences were not merely slowed down. The observed effect on correctly recalling the sequences shows that inhibition affected memory not only the speed of execution.

In contrast, for T items as compared to B items, a benefit of movement initiation occurred. In Experiment 1, slower initiation of NT items arose as well. Instead of a significantly slowed movement initiation of NT items, a recall accuracy effect appeared for NT items in Experiment 2. This documents a speed-accuracy tradeoff. When items were memorized sufficiently well, inhibitory control processes probably slowed down access to and execution of stored sequence representations (Experiment 1), but when items were stored less well, voluntary suppression of the item lead to a drop in accurately recalling the item (Experiment 2). The slowing of execution after a sequence has been accessed points to an impact of inhibition on the memory representation itself and not simply on the association of the respective sequences to their stimuli. Moreover, the accuracy with regard to recall of the whole sequence was affected by suppression. Accuracy and reaction-time analyses both suggest, therefore, sequence representations were inhibited, not individual features of these representations.

In the learning trials, all sequences were memorized within one and the same category, the right hand as the common effector. So, all right-hand related motor programs were also activated in the presence of a retrieval cue. This common feature then may have raised an interference potential between these items in the subsequent *think/no-think* practice and task. Studies on retrieval-induced forgetting (Tempel & Frings, 2013, 2017) and selective directed forgetting (Schmidt et al., 2021) suggest that the inhibition process causing those effects depended on the strength of potential interference among motor sequences encoded as one set of items. Future studies may elucidate a potential interference-dependence of *motor SIF* effects as well, for example by comparing different categorizing principles, such as which effectors are involved (e. g., the left versus the right hand). Furthermore, it remains to be examined whether stopping awareness of the sequence was causally necessary for the inhibition effect, or whether stopping the action itself was enough. A similar effect could, in principle, arise with instructions that do not require the avoidance of recollection. This possibility seems unlikely, however, because merely preventing the overt expression of an action still allows it to be retrieved and imagined covertly. A large body of work indicates that covertly retrieving motor actions (i.e., “mental practice”) significantly strengthens them and improves their execution (e.g., Agosti & Sirico, 2020; Feltz & Landers, 1983; Feltz, Landers, & Becker, 1988; Lotze & Halsband, 2006). Here, retrieval suppression not only did not strengthen the associated action, but also rendered performance worse than it would have been had cues to the action not been presented at all (*baseline*) during the *think/no-think* task.

In this motor adaption of the *think/no-think* task, we demonstrated a motor analog to SIF, suggesting similar effects of inhibitory control on the retention of traces within different representational systems. The present evidence for *motor SIF* adds to evidence that inhibitory processes contribute to forgetting of motor actions in long-term memory (Schmidt et al., 2021; Tempel & Frings, 2013, 2017). Together this points to a common principle: inhibitory mechanisms act on the very memory representation itself, across modalities, independent of the representational system.

Publicly available data set:

https://osf.io/xqh4j/?view_only=da175c4e7ae8408aa1478cf8122c2575

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References

Abrahamse, E., Ruitenberg, M., De Kleine, E., & Verwey, W. (2013). Control of automated behavior: insights from the discrete sequence production task. *Frontiers in Human* Neuroscience, *7*, 82. DOI: 10.3389/fnhum.2013.00082

Agosti, V.; Sirico, M. (2020). Motor imagery as a tool for motor learning and improving sports performance: A mini review on the state of the art. *Sport Science, 13*, 13–17.

Anderson, M.C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Nature*, *410*, 366–369. DOI: 10.1038/35066572

Anderson, M.C., & Hanslmayr, S. (2014). Neural mechanisms of motivated forgetting. *Trends in Cognitive Sciences, 18*, 279–292. DOI: 10.1016/j.tics.2014.03.002

Anderson, M.C., & Hulbert, J.C. (2021). Active forgetting: Adaptation of memory by prefrontal control. *Annual Review of Psychology, 72*, 1-36. DOI: 10.1146/annurev-psych-072720-094140

Apšvalka, D., Ferreira, C.S., Schmitz, T.W., Rowe, J.B., & Anderson, M.C. (2022). Dynamic targeting enables domain-general inhibitory control over action and thought by the prefrontal cortex. *Nature Communications, 13,* 274 (2022). DOI: 10.1038/s41467-021-27926-w

Castiglione, A., Wagner, J., Anderson, M.C., Aron, A.R. (2019). Preventing a thought from coming to mind elicits increased right frontal beta just as stopping action does. *Cerebral Cortex*, *29(5)*, 2160–2172. DOI: 10.1093/cercor/bhz017

Catarino, A., Küpper, C. S., Werner-Seidler, A., Dalgleish, T., & Anderson, M. C. (2015). Failing to forget: Inhibitory-control deficits compromise memory suppression in posttraumatic stress disorder. *Psychological Science, 26*, 604–616. DOI: 10.1177/0956797615569889

Depue, B.E., Orr, J.M., Smolker, H.R., Naaz, F., & Banich, M.T. (2016). The Organization of Right Prefrontal Networks Reveals Common Mechanisms of Inhibitory Regulation Across Cognitive, Emotional, and Motor Processes. *Cerebral Cortex*, *26*, 1634-1646. DOI: 10.1093/cercor/bhu324

Feltz, D.L., & Landers, D.M. (1983). The effects of mental practice on motor skill learning and performance: A meta-analysis. *Journal of Sport Psychology*, *5*, 25-57.

Feltz, D.L., Landers, D.M., & Becker, B.J. (1988). *A revised meta-analysis of the mental practice literature on motor skill learning*. Washington, DC. National Academy Press.

Gagnepain, P., Henson, R.N., & Anderson, M.C. (2014). Suppressing unwanted memories reduces their unconscious influence via targeted cortical inhibition. *Proceedings of the National Academy of Sciences of the United States of America, 111*, E1310–E1319. DOI: 10.1073/pnas.1311468111

Gagnepain, P., Hulbert, J. & Anderson, M. C. (2017). Parallel regulation of memory and emotion supports the suppression of intrusive memories. The Journal of Neuroscience, 37, 6423–6441. DOI: 10.1523/JNEUROSCI.2732-16.2017

Guo, Y., Schmitz, T.W., Mur, M., Ferreira, C.S., Anderson, M.C. (2018). A supramodal role of the basal ganglia in memory and motor inhibition: Meta-analytic evidence. *Neuropsychologia*, *108*, 117-134. DOI: 10.1016/j.neuropsychologia.2017.11.033

Hertel, P., Maydon, A., Ogilvie, A., & Mor, N. (2018). Ruminators (unlike others) fail to show suppression-induced forgetting on indirect tests of memory. *Clinical Psychological Science, 6*, 872–881. DOI: 10.1177/2167702618785339

Hu, X., Bergstrom, Z. M., Gagnepain, P., & Anderson, M. C. (2017). Suppressing unwanted memories reduces their unintended influences. *Current Directions in Psychological Science, 26*, 197–206. DOI: 10.1177/0963721417689881

Kim, K., & Yi, D.J. (2013). Out of mind, out of sight: Perceptual consequences of memory suppression. *Psychological Science, 24*, 569–574. DOI: 10.1177/0956797612457577

Küpper, C. S., Benoit, R. G., Dalgleish, T., & Anderson, M. C. (2014). Direct suppression as a mechanism for controlling unpleasant memories in daily life. *Journal of Experimental Psychology: General, 143*, 1443–1449. DOI: 10.1037/a0036518

Levy, B. J., & Anderson, M. C. (2012). Purging of memories from conscious awareness tracked in the human brain. *The Journal of Neuroscience, 32*, 16785–16794. DOI: 10.1523/JNEUROSCI.2640-12.2012

Lotze, M., & Halsband, U. (2006). Motor imagery. *Journal of Physiology, 99*, 386–395. DOI: 10.1016/j.jphysparis.2006.03.012

Marsh, L.C., & Anderson, M.C. (in press). Inhibition as a cause of forgetting. In A. Wagner & M. Kahana (Eds), *Oxford Handbook of Memory.*

Mary, A., Dayan, J., Leone, G., Postel, C., Fraisse, F., Malle, C., Vallée, T., Klein-Peschanski, C., Viader, F., de la Sayette, V., et al. (2020). Resilience after trauma: the role of memory suppression. *Science, 367*, 6479, 734-735. DOI: 10.1126/science.aay8477

Peirce, J., Gray, J.R., Simpson, S. et al. (2019) PsychoPy2: Experiments in behavior made easy. Behavior Research Methods, 51, 195–203. DOI: 10.3758/s13428-01801193-y

Schmidt, M., Frings, C., & Tempel, T. (2021). Selective directed forgetting of motor sequences. *Acta Psychologica, 218*, 103352. DOI: 10.1016/j.actpsy.2021.103352

Schmitz, T.W., Correia, M.M., Ferreira, C.S., Prescott, A. P., & Anderson, M. C. (2017). Hippocampal GABA enables inhibitory control over unwanted thoughts. *Nature Communications, 8*, 1311. DOI: 10.1038/s41467-017-00956-z

Taubenfeld, A., Anderson, M.C. & Levy, D.A. (2019). The impact of retrieval suppression on conceptual implicit memory, Memory, 27:5, 686-697. DOI: 10.1080/09658211.2018.1554079

Tempel, T., & Frings, C. (2013). Resolving interference between body movements: Retrieval-induced forgetting of motor sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39,* 1152–1161. DOI: 10.1037/a0030336

Tempel, T., & Frings, C. (2014). Forgetting motor programmes: Retrieval dynamics in procedural memory. *Memory, 22*, 1116-1125. DOI: 10.1080/09658211.2013. 871293

Tempel, T., & Frings, C. (2017). Retrieval-induced forgetting is retrieval-modality specific. *Cognition, 162*, 143-152. DOI: 10.1016/j.cognition.2017.02.005

Wang, Y., Luppi, A., Fawcett, J., and Anderson, M.C. (2019). Reconsidering unconscious persistence: suppressing unwanted memories reduces their indirect expression in later thoughts. *Cognition, 187*, 78–94. DOI: 10.1016/j.cognition.2019.02.016

5. Allgemeine Diskussion

In drei Artikeln sind wir der Frage nachgegangen, ob sich aus dem deklarativen Gedächtnis bekannte kontextuelle und inhibitorische Effekte auch im motorischen Gedächtnis finden lassen, und konnten dies in mehreren Experimenten bestätigen.

Im ersten von drei *peer reviewed* Artikeln setzten wir uns mit der allgemeinen Bedeutung von externen Kontextmerkmalen für einen motorischen Abruf auseinander. Zwei Sätze motorischer Sequenzen waren unter zwei verschiedenen Kontextbedingungen intentional gelernt und unter Bedingungen der vollständigen oder teilweisen Kontextwiederherstellung oder -beibehaltung erinnert worden. Verglich man die ersten acht mit den zweiten acht erinnerten Sequenzen, unterschied sich der Verlauf der Erinnerungsgenauigkeit für drei Bedingungen signifikant, nur in der Kontextwechselbedingung zeigte sich kein signifikanter Unterschied zwischen den ersten und zweiten acht erinnerten Sequenzen.

Die beiden weiteren peer reviewed Artikel wendeten sich dann der kognitiven Inhibition (nach MacLeod, 2007) motorischer Gedächtnisinhalte zu. Im zweiten Artikel überprüften wir in einem drei motorische Listen umfassenden LMDF-Ansatz (Bjork, 1970), ob sich selektives gerichtetes Vergessen in genau nur der einen Bedingung der zweiten Liste zeigt, in der wir das Zustandekommen von kognitiver Inhibition ermöglichten, indem wir nur hier ein Interferenzpotenzial zwischen Liste Zwei und Drei zuließen. Selektives gerichtetes Vergessen trat genau nur für diese Bedingung auf, was eindeutig auf Inhibition als Ursache deutet.

Im dritten Artikel schließlich begutachteten wir, ob sich die im deklarativen Gedächtnis bekannten Effekte der willentlichen Unterdrückung von Gedächtnisinhalten auch in einer motorischen Adaptation des TNT-Paradigmas (Anderson & Green, 2001) finden lassen. Teilnehmende lernten (bis zu einem Kriteriumswert an Erinnerungsgenauigkeit oder einem Durchgangslimit) Buchstaben zu Drei-Finger Sequenzen der rechten Hand zu assoziieren. Danach begann die *think/no-think* Phase. Eine grüne Hand mit Konsonant indizierte hierin die Sequenz zu erinnern und auszuführen, eine rote Hand mit Konsonant untersagte die Ausführung und war mit der zusätzlichen Aufforderung verbunden, bestmöglich jeden Gedanken an diese Sequenz zu vermeiden. War das anfängliche Kriterium hoch angesetzt, so zeigte sich ein Effekt willentlicher Unterdrückung der Sequenzen in einer signifikanten Verlangsamung derer Zugänglichkeit und tendenziell der Ausführung, nicht aber in der Erinnerungsgenauigkeit. Wenn das anfängliche Kriterium niedriger angesetzt war, zeigte sich der Effekt willentlicher Unterdrückung auch in der Erinnerungsgenauigkeit und weiterhin in einer signifikanten Verlangsamung der Ausführung willentlich unterdrückter motorischer Inhalt.

5.1. Ergebnisdiskussion Kontext und motorisches Erinnern

Ausgehend von der zahlreich belegten Abhängigkeit des deklarativen Gedächtnisabrufs von kontextuellen Bedingungen (etwa Godden & Baddeleys Studie von 1975) versuchten wir eine Auswirkung von externen Kontextbedingungen auf den Abruf motorischer Inhalte zu belegen. Zwei Sätze zu je acht verschiedenen Drei-Finger Bewegungen der rechten Hand wurden von den Teilnehmenden in zwei auffällig unterschiedlich gehaltenen Kontextbedingungen encodiert. Im abschließenden Test, in dem wir den Kontext wiederherstellten, beibehielten oder beides nur teilweise unternahmen, erwarteten wir, dass sich der Abrufverlauf gemäß der Theorie der zwei Gesichter des Gedächtnisabrufs verhält (Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010). Diese sagt einen ausbreitend aktivierenden, selbstpropagierenden seriellen Verlauf des Gedächtnisabrufs im Falle eines Kontextwechsels vorher. Bei Beibehaltung des Kontexts sollte der Abruf einen selbstlimitierenden inhibierenden Verlauf haben. Genau dieses Muster konnten wir in unseren Ergebnissen beobachten (siehe **Figur 4**, Seite 27), der Abruf zeigte sich als eine Funktion der *Output*-Position.

Für die ersten drei Bedingungen, die wir in der Planung als Kontextbeibehaltung aufgefasst hatten, fällt die Erinnerungsleistung von den zuerst erinnerten acht Sequenzen auf die zuletzt erinnerten acht Sequenzen stets signifikant ab, der serielle Verlauf der Leistung nimmt die von uns so erwartete selbstlimitierende Form an. In der *no change* – Hauptbedingung wurden die Teilnehmenden im Test wieder auf den Arbeitsplatz von der Lernphase L2 gesetzt und im L2-Kontext getestet. In der *neutral no change* – Bedingung war der einzige Unterschied zu *no change*, dass die Teststimuli und Instruktionen im Vergleich zu L2 einen neuen Stil hatten, der auch nicht in L1 vorgekommen war. Die Reaktionstasten waren die von L2. Wir erwarteten diesen neutralen Stil als nicht ausreichend um einen Kontextwechsel zu produzieren, und die Ergebnisse dieser Bedingung verhielten sich auch ähnlich zur *no change* – Gruppe. Dieselben neutralen Stimuli verwendeten wir in der *neutral change* – Gruppe, wir hatten erwartet, dass diese einen Kontextwechsel zurück zu L1 verhindern könnten, trotz L1-Reaktionstasten. Das Ergebnismuster weist auch einen selbstlimitierenden Verlauf auf, die neutralen Stimuli haben einen Kontextwechsel also offensichtlich verhindert.

Nur in der *change* – Hauptbedingung, in der wir den kompletten Testkontext zurück auf L1 gestellt hatten, zeigte sich das Muster eines selbstpropagierenden Verlaufs. Von einem anfänglich niedrigeren Niveau als in den anderen drei Gruppen fiel die Erinnerungsleistung nicht wesentlich ab, das Muster weist einen selbstpropagierenden Verlauf und als einzige

Gruppe keinen signifikanten Unterschied zwischen den ersten und zweiten acht erinnerten Sequenzen auf. Unsere Ergebnisse bestätigten die Vorhersagen der Theorie der zwei Gesichter des Gedächtnisabrufs (Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010) bezüglich des Abrufverlaufs bei einem Kontextwechsel oder bei Kontextbeibehaltung für motorische Gedächtnisrepräsentationen.

Der selbstlimitierende Verlauf in der *neutral change* – Gruppe zeigt die Bedeutung sowohl der visuellen intentionalen (Test-)Stimuli als auch der inzidentellen Stimuli (Schrift, Farbe, Hintergrund der Instruktionen; Wright & Shea, 1991) für das Zustandekommen eines Kontextwechsels. Eine moderate Änderung in diesen beiden Faktoren verhinderte das Zustandekommen eines Kontextwechsels, das Abrufmuster zeigt ebenso einen selbstlimitierenden Verlauf. Nur wenn wirklich alle Kontextfaktoren auf L1 zurückgestellt wurden trat dieser Kontextwechsel auch auf (*change* – Gruppe) und eliminierte so das typische Muster eines starken Abfalls der Leistung von T1 auf T2, zeigte stattdessen einen selbstpropagierenden Verlauf. In der *neutral no change* – Bedingung dagegen gerieten diese moderaten Änderungen in Schrift, Farbe, Hintergrund und Teststimuli in keinen Konflikt mit den anderen beibehaltenen Kontextstimuli, genügten nicht einen Kontextwechsel zu verursachen. Ruitenberg et al. (2012) merkten in ihrem inzidentellen Lernsetting zur Kontextabhängigkeit einer motorischen Aufgabe an, dass die Kontexteffekte in einer DSP (*discrete sequence production*) - Aufgabe möglicherweise nicht nur eine Abruferleichterung per Kontextwiederherstellung reflektieren, sondern auch den effektiven Umgang mit irrelevanten Stimuli. Sie nannten das kontextabhängige Filterung. Vielleicht wurden unsere neutralen Stimuli in der *neutral no change* Bedingung als irrelevant entsprechend kontextabhängig (zugunsten vom L2-Kontext) ausgefiltert. Die kontextuellen L1 und L2 Merkmale selbst konnte man nicht ausfiltern, da diese den Kontext selbst definierten. Für einen tatsächlichen Kontextwechsel jedenfalls müssen nach unseren Ergebnissen alle intentionalen und inzidentellen Stimuli umgestellt werden.

Ähnliches haben Laub und Frings (2018) in ihrer Untersuchung zur distraktorbasierten Handlungskontrolle beobachtet. Wird ein Stimulus mit einem irrelevanten Distraktor präsentiert, so kann der Distraktor die encodierte motorische *Response* abrufen. Distraktorbasierter Abruf trat bei Laub und Frings (2018) nur in jenen Bedingungen auf, in denen die Anzahl der Distraktoren im *Prime* und in der *Probe* identisch waren. Variierte man deren Anzahl zwischen Encodierung und Abruf zeigte sich kein distraktorbasierter Abruf.

Frings et al. (2020) gehen in ihrem BRAC-Modell (*Binding and Retrieval in Action*

Control), das auf existierenden Modellen zur Handlungskontrolle aufbaut (etwa TEC, *theory of event coding*; Hommel et al., 2002), davon aus, dass Eigenschaften der Stimulus-Umgebung (S; Stimulus, Kontext, Hinweisreiz), die *Response* (R; Entschluss, Effektor) in dieser Umgebung und die nachfolgenden Effekte (E; perzeptuell und affektiv) in einem *event-file* integriert und verbunden werden. Wiederholungen in irgendeiner dieser S, R oder E Eigenschaften lösen nun den Abruf aller zuvor encodierter *event-files* aus, deren Code diese Eigenschaften enthält. Das kann sich auf die gegenwärtige Ausführung auswirken. Ob dieser Abruf nun mit Ausführungskosten oder einem Ausführungsnutzen verbunden ist kommt auf die Umstände an. Übertragen auf Laub und Frings (2018) oder auf unser Experiment bedeutet es, dass sich die Effekte beider Experimente nur bei vollständiger Übereinstimmung der Stimulus-Bestandteile der *event-files* in Encodierung und Abruf eingestellt haben.

In ihrem zweiten Experiment hatten Wright und Shea (1991) gezeigt, dass sich Änderungen in den intentionalen oder inzidentellen Stimuli auf eine einfachere Aufgabe nicht mehr auswirkten. Teilnehmende konnten die Sequenzen in einer dritten Bedingung sogar ohne die Präsentation irgendeines intentionalen Stimulus ausführen, was auf ausgebildete starke Assoziationen zwischen den inzidentellen Stimuli und den Sequenzen deutet. Auch in unserem Experiment waren diese starken Assoziationen wohl entwickelt worden und hatten dazu geführt, dass die beiden Sätze in zwei verschiedenen Kontexten wahrgenommen wurden, die sich durch den Gebrauch dieser Stimuli wiederherstellen oder beibehalten ließen.

Die Theorie der zwei Gesichter des Gedächtnisabrufs (Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010) nimmt im Wesentlichen an, dass der Wechsel im Kontext graduiert über die relativen Anteile von Blockierung/Inhibition oder eben kontextuellen Abrufs in der Gesamtleistung entscheidet. Ist der Wechsel im Kontext also eher niedrig oder moderat, kann es durchaus sein, dass der selbstpropagierende Effekt von T1 auf T2 eher niedrig ausfällt oder sich gar nicht einstellt. In unserem Experiment beobachteten wir einen neutralen Effekt. Wir ließen unsere Teilnehmenden zwei Sätze motorischer Sequenzen an zwei verschiedenen Arbeitsplätzen im selben Raum ausführen. Da ist noch erheblicher Spielraum, den Kontextwechsel wesentlich drastischer zu gestalten. Es ist auch denkbar die inzidentellen und intentionalen Stimuli wesentlich eindringlicher unterschiedlich zu gestalten, als wir das taten. Weitere Forschung kann deren individuellen Beiträge und deren Wirksamkeit sicher noch weiter aufklären.

Die Inhalte des wiederhergestellten Kontexts zeigten sich nicht als unmittelbar per Kontextwechsel zugänglich. Der T1 Abruf in der Kontextwechsel-Bedingung (*change*) ist deutlich niedriger als der T1 Abruf im beibehaltenen Kontext (*no change*). Der Zugang wird erst über die weiteren Abrufversuche erfolgreicher, der Kontexteffekt braucht Zeit sich etablieren zu können, der erfolgreiche erste Abruf entsprechender Elemente aktiviert sich ausbreitend andere Elemente dieses Kontexts, was deren Zugänglichkeit nachfolgend erhöht.

Hinsichtlich unserer Ausgangsfragestellung können wir abschließend feststellen, dass sich Effekte einer Kontextabhängigkeit der Erinnerungsleistung auch im motorischen Gedächtnis abbilden. Diese Effekte verhalten sich auch im motorischen Gedächtnis so, wie es die Theorie der zwei Gesichter des Gedächtnisabrufs (etwa Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010) vorhersagt. Dies legt nahe, dass die Gedächtnisprozesse der sich ausbreitenden Aktivierung oder der Inhibition (Roediger & Neely, 1982) auch den motorischen Gedächtnisabrufverlauf so moderieren, wie es für den deklarativen bekannt ist.

Nachdem Kontext und Inhibition bedeutsame Faktoren prominenter Erklärungsmodelle zum gerichteten Vergessen sind (für einen Überblick siehe MacLeod, 1998), wandten wir uns im zweiten Artikel nun diesem Paradigma zu. Der inhibitorische Erklärungsansatz zum gerichteten Vergessen geht von einem per Inhibition aufgelösten Interferenzpotenzial aus, was zu den Kosten führt (etwa Geiselman et al., 1983). Der Kontextwechselansatz (Sahakyan & Kelley, 2002) führt die Kosten dagegen auf eine Diskrepanz zwischen dem Encodier- und Abrufkontext zurück. In einem drei kurze motorische Sätze umfassenden Versuchsaufbau gingen wir der Frage Kontext oder Inhibition als Ursache eines potenziellen selektiven gerichteten Vergessens für diese Inhalte nach.

5.2. Ergebnisdiskussion selektives gerichtetes Vergessen motorischer Inhalte

Der zweite Artikel dieser Dissertation setzt sich mit der Fragestellung auseinander, ob sich das selektive gerichtete Vergessen (LMDF, Bjork, 1970; für einen Überblick siehe MacLeod, 1998) eines kleinen Satzes motorischer Sequenzen (L2) genau in der einen Bedingung eines drei Sätze umfassenden Versuchsaufbaus zeigt, in der wir das zur Entstehung von Inhibition notwendige Interferenzpotenzial (siehe Anderson, 2005) mit nachfolgend zu encodierendem Material ermöglichten. Dies würde für Inhibition als Ursache des selektiven gerichteten Vergessens motorischer Inhalte in unserem Experiment sprechen.

Unser Versuchsaufbau war so konzipiert, dass sich Ergebnismuster eindeutig einer der prominenten Erklärungstheorien zum gerichteten Vergessen zuordnen ließen. Die erste Liste war stets mit der linken Hand auszuführen, die zweite stets mit der rechten Hand. Das sollte die Diskriminierbarkeit der Listen erhöhen und so eine potenzielle gezielte Inhibition erleichtern. Ebenso stets war der mittlere Satz entweder zu behalten oder zu vergessen. Als zweiter Faktor war in einer Bedingung der dritte Satz (L3) mit derselben Hand auszuführen wie L2, in der anderen Bedingung mit der anderen Hand. Da die Hände als distinkte Kategorien zur Gedächtnisorganisation motorischer Inhalte angesehen werden können (Tempel et al., 2016; Tempel & Frings, 2014a, 2014b, 2015, 2017), ist durch diesen zweistufigen Faktor davon auszugehen, dass wir im Falle eines Wechsels der Hand von L2 auf L3 ein niedriges Interferenzpotenzial zwischen diesen beiden motorischen Sätzen generierten. Wurde der Effektor dagegen zwischen L2 und L3 wiederholt, sollte ein hohes Interferenzpotenzial zwischen diesen beiden Sätzen bestehen. Dieses Interferenzpotenzial wird nun zum Ziel eines adaptiven Inhibitionsmechanismus und durch Inhibition von L2 aufgelöst, was zu den Kosten im gerichteten Vergessen führt, so die allgemeine Theorie des inhibitorischen Erklärungsmodells zum gerichteten Vergessen (Anderson, 2005; Anderson & Hanslmayr, 2014; Bäuml et al., 2008; Geiselman et al., 1983; Hanslmayr et al., 2012). Inhibition sollte also nur auftreten, wenn nach dem Vergessen-Signal zusätzlich potenziell interferierendes Material encodiert wird. Conway et al. (2000) und Pastötter und Bäuml (2007, 2010) zeigten ein entsprechendes Ausbleiben der Kosten, wenn nach dem Vergessen-Signal eine unzureichende Menge zusätzlichen Materials zu encodieren war. Mit unserem zweiten Faktor schalteten wir dieses zum Zustandekommen von Inhibition notwendige Interferenzpotenzial also entweder zu oder ab. Gemäß des inhibitorischen Erklärungsansatzes erwarteten wir ein selektives gerichtetes Vergessen von L2 (Kosten) genau nur in der einen Bedingung mit einem hohen Interferenzpotenzial zu nachfolgend zu encodierendem Material. Dieses Ergebnis stellte sich ein (siehe **Figure 3**, Seite 45), weist somit also eindeutig auf Inhibition als Ursache für die Entstehung der Kosten in unserem Experiment hin. Die hohe Interferenz, die nur in dieser einen Bedingungskonstellation vorhanden war, wurde per Inhibition von L2 nur in genau dieser einen Gruppe aufgelöst, um das Gedächtnis für das zu behaltene Material (L3) zu verbessern (Anderson, 2003).

Nicht nur haben wir damit einen Nachweis selektiven gerichteten Vergessens im motorischen Gedächtnis per Inhibition erbracht, die Abruf-Inhibitionstheorie (Geiselman et al., 1983) für motorische Gedächtnisinhalte bestätigt, unser Ergebnismuster schließt auch die beiden anderen prominenten Erklärungsmodelle zum gerichteten Vergessen als verantwortliche

Mechanismen für unser beobachtetes selektives gerichtetes Vergessen von L2 aus.

Bjorks (1970) Ein-Faktor-Modell eines selektiven Lernabrufs der zu erinnernden Materialien sagt selektives gerichtetes Vergessen für unseren Versuchsaufbau in beiden Gruppen der Effektormanipulation vorher (*switch* und *no-switch*). Da nur die zu erinnernden Sequenzen selektiv geübt werden, sollte das Vergessen von L2 (Kosten) in beiden Gruppen auftreten, unabhängig von einem bestehenden oder nicht bestehenden Interferenzpotenzial. Das geschah nicht. Aguirre et al. (2017) fanden ebenso Evidenz gegen Bjorks (1970) Modell. In ihrem Experiment 1 erhöhten sie die Ladung des Arbeitsspeichers mittels einer artikulatorischen Unterdrückungsaufgabe, was sich auf einen selektiven Lernabruf auswirken sollte. Selektives gerichtetes Vergessen trat trotzdem auf, was nahelegt, dass "selektiver Lernabruf keine Schlüsselrolle bei der Entstehung von selektivem gerichteten Vergessen spielt" (Seite 5).

Sahakyan und Kelley (2002) in ihrem Kontextwechsel-Ansatz gehen von einem durch die listenbezogene Vergessen-Instruktion ausgelösten mentalen Kontextwechsel aus. Dieser interne Kontextwechsel soll nun die Zugänglichkeit allen vor dem Vergessen-Signal gelernten Materials mindern. Wäre diese Erklärung in unserem Aufbau zutreffend, hätten wir nicht-selektives Vergessen von L1 und L2 beobachten müssen. Der L1-Abruf in unserer *no-switch* – Gruppe zeigte aber keine signifikanten Unterschiede zwischen den Bedingungen "Behalten" und "Vergessen". Der Kontextwechsel-Ansatz kann unser Ergebnismuster nicht erklären.

Dass kein selektives gerichtetes Vergessen in der Bedingung auftrat, die wenig oder keine Interferenz zwischen L2 und L3 ermöglichte (*switch*), legt nahe, dass die Kosten im gerichteten Vergessen nur auftreten, wenn nachfolgend encodiertes Material in Konkurrenz zu diesem treten, interferieren kann. Tempel und Frings (2013) benutzten die Hände in ähnlicher Weise als Kategorien zur Gedächtnisorganisation motorischer Sequenzen in ihrer Untersuchung zum abrufinduzierten Vergessen (RIF, *retrieval induced forgetting*). Anderson et al. legten 1994 dar, dass der Abrufprozess an sich Vergessen verursachen kann, das bloße Erinnern eines Inhalts einen assoziierten anderen Inhalt vergessen macht. Diese empirische Beobachtung wird abrufinduziertes Vergessen (oder RIF) genannt. Tempel und Frings (2013) belegten abrufinduziertes Vergessen für motorische Repräsentationen. Teilnehmende lernten ähnlich wie hier zwei Sätze motorischer Sequenzen, die entweder mit der linken oder mit der rechten Hand auszuführen waren. In einer anschließenden Abrufübung waren die Hälfte der Sequenzen einer Hand mehrmals zu erinnern. Dies führte zum Vergessen der anderen Hälfte der Sequenzen dieser Hand. Verglich man die Erinnerungsgenauigkeit an diese andere Hälfte in einem abschließenden Test mit der respektiven Hälfte der anderen Hand, wurden diese schlechter erinnert. Dieses und andere Ergebnisse (Tempel et a. 2016; Tempel & Frings, 2014a, 2014b, 2015, 2017) legen nahe, dass ein adaptiver Inhibitionsmechanismus dieses abrufinduzierte Vergessen verursacht, der einsetzt, wenn in einem selektiven Abruf Interferenz zwischen Inhalten verschiedener Sätze entsteht, um diese zu beseitigen. Der Abruf löste Interferenz stets innerhalb einer Hand aus, nie aber trat Interferenz zwischen den Elementen verschiedener Hände auf. Diese Ergebnisse und das Ausbleiben eines selektiven gerichteten Vergessens in der *switch* - Bedingung spricht dafür, dass die Hände in unserem Experiment als Faktor zur Interferenzinduktion verwendet werden können. Interferenzabhängigkeit ist eines der vier Postulate der Inhibitionstheorie (Anderson, 2003). Dies legt nahe, dass sich dieses Postulat auf motorische Sequenzen übertragen lässt (auch bereits im abrufinduzierten Vergessen, Tempel & Frings, 2013, 2017).

Zwar ließen wir Teilnehmende im Test raten, wenn diese die vier Sequenzen einer Liste nicht erinnerten, was einen Beitrag des impliziten Gedächtnisses zu deren Erinnerungsleistung ermöglichte, wir halten einen fundamentalen Einfluss solcher impliziten Anteile auf die Effekte des selektiven gerichteten Vergessens aber für relativ unwahrscheinlich. MacLeod (1989) hat bereits gezeigt, dass auch das implizite Gedächtnis Effekte gerichteten Vergessens aufweist. In diesem Experiment wiesen wir das erste Mal selektives gerichtetes Vergessen motorischer Repräsentationen in einem Versuchsaufbau nach, der eindeutig auf kognitive Inhibition als Ursache dieser L2-Kosten hinweist.

Obwohl wir also im ersten Artikel eine kontextabhängige Erinnerungsleistung für motorische Sequenzen belegen konnten, wurden die motorischen Sequenzen in unserem zweiten Artikel nicht so erinnert, wie es der Kontextwechselansatz (Sahakyan & Kelley, 2002) zum gerichteten Vergessen vorhersagt. Hier hatten unsere Ergebnisse eindeutig die Abruf-Inhibitionstheorie (Geiselman et al., 1983) für motorische Gedächtnisinhalte bestätigt.

5.3. Ergebnisdiskussion zur willentlichen Unterdrückung motorischer Inhalte

Im letzten Artikel dieser Dissertation befassen wir uns mit SIF (*suppression induced forgetting*). Wir unternahmen zwei Experimente, um diesen Effekt der willentlichen Unterdrückung des Gedächtnisabrufs im motorischen Gedächtnis zu untersuchen. Anderson und Green (2001) konnten zeigen, dass inhibitorische Kontrollprozesse, die sich auf unerwünschte deklarative Inhalte zu deren willentlichen Unterdrückung richten, den nachfolgenden Abruf dieser Inhalte erschwerten. Inhibition lässt sich in diesem Paradigma wesentlich direkter als etwa in RIF untersuchen, da die Teilnehmenden direkt instruiiert werden, Inhalte willentlich zu unterdrücken.

Wir orientierten uns am Original-Paradigma dieses Versuchsaufbaus, kurz TNT (*Think/No-Think*) genannt. Teilnehmende in unseren beiden Experimenten lernten zuerst Buchstaben mit Drei-Finger Sequenzen zu assoziieren (siehe unteren Teil von **Abbildung 1**, Seite 12). Unmittelbar daran begann die TNT-Phase, in der zwei verschiedene Verhaltensweisen instruiert waren, die durch die Farbe der Buchstaben-Hand Hinweisreize indiziert waren. Grün gehaltene Hand-Konsonant Kombinationen hatten einen *go* – Charakter, die zum Konsonant assoziierte Sequenz sollte also umgehend erinnert und ausgeführt werden (*think*). Rote Hand-Konsonant Kombinationen waren dagegen mit einem *no-go* – Charakter verbunden (TNT ist eine Adaptation des *go/no-go* Paradigmas), der sogar für den Gedächtnisabruf gelten sollte (*no-think*). Die assoziierte Sequenz sollte bestmöglich also sogar daran gehindert werden den Teilnehmenden bewusst zu werden, - und natürlich erst recht nicht ausgeführt werden. Wenn sich der willentliche Versuch die Sequenzen im Abruf der TNT-Phase zu unterdrücken inhibitorischer Kontrolle bedient, sollten diese in einem finalen Abruf auch schlechter erinnert werden als *baseline* Sequenzen, die in dieser TNT-Phase nicht vorgekommen waren. Dieses Ergebnis stellte sich in Experiment 1 jedoch nicht in der Erinnerungsgenauigkeit ein (siehe **Figure 2**, links oben, Seite 59). Effekte willentlich rekrutierter Unterdrückungsprozesse zeigten sich stattdessen in den Reaktionszeiten.

Abrahamse et al. (2013) gehen in ihrem Zwei-Prozessoren Modell zur geübten Handlungsausführung von einem kognitiven und einem Motorprozessor aus. Der kognitive Prozessor ist für die Sequenzinitiation zuständig. Er ruft die zum Stimulus assoziierte *Response* auf, übersetzt diesen Stimulus also in das entsprechende motorische Programm, und lädt dieses dann in den Motorprozessor, bereitet die Ausführung vor. Initiation entspricht in unserem Aufbau dem ersten Tastendruck (siehe **Figure 2**, untere Hälfte, Seite 59) und dauert typischerweise wesentlich länger als die nachfolgenden Tastendrucke. Die Initiation von T-Sequenzen war signifikant schneller als die von B-Sequenzen, die Initiation von NT-Sequenzen war signifikant langsamer als die von B-Sequenzen. Der Motorprozessor seinerseits führt dieses auf einige Elemente limitierte Programm dann autonom aus (*execution* in **Figure 2**, untere Hälfte, Seite 59). In unserem Aufbau entspricht dies den Tastendrucken Zwei und Drei. Hier zeigte sich der Unterschied zwischen T und NT signifikant, aber der Vergleich B zu NT zeigte nur einen Trend zur Verlangsamung von NT. Entgegen unserer Erwartung wurden wiederholt unterdrückte Sequenzen nicht schlechter erinnert, obwohl die Reaktionszeiten einen Effekt wiederholter Unterdrückung indizierten. Diese diskrepante Beobachtung könnte auf unser anfängliches Lernen zurückzuführen sein. Die Konsonant-Sequenz Paare waren sehr gut trainiert worden, was diese robust gegen ein Vergessen gemacht haben könnte, sich der Effekt also nur in den Reaktionszeiten einstellen konnte. Um diese Hypothese zu überprüfen, unternahmen wir Experiment 2.

In Experiment 2 erhöhten wir die Anzahl der Sequenzen und reduzierten den Lernaufwand. Hier zeigte sich nun ein Effekt in der abschließenden Erinnerungsgenauigkeit. NT-Sequenzen wurden signifikant schlechter erinnert und signifikant langsamer ausgeführt als B-Sequenzen. Beide Ergebnisse zusammen beschreiben ein Ausgleichsverhalten zwischen Geschwindigkeit und Erinnerungsgenauigkeit im Abruf der willentlich unterdrückten Sequenzen. Waren die Sequenzen anfänglich gut und genau genug encodiert worden, so haben willentlich rekrutierte inhibitorische Prozesse wahrscheinlich nur die Zugänglichkeit signifikant und die Ausführung der Sequenzen tendenziell unterdrücken können (Experiment 1). War diese Encodierung dagegen weniger gut und genau, so konnten diese per willentlicher Unterdrückung rekrutierten inhibitorischen Prozesse sowohl die Erinnerung an diese Sequenzen abreißen lassen als auch deren Ausführung signifikant verlangsamen (Experiment 2).

Im zweiten veröffentlichten Artikel dieser Dissertation haben wir zeigen können, dass ein selektives gerichtetes Vergessen nur auftrat, wenn wir ein Interferenzpotenzial zwischen der Zielliste (L2) und nachfolgend zu encodierendem Material (L3) aufbauten, indem beide mit derselben Hand auszuführen waren. In diesem Artikel hier waren alle Sequenzen immer mit derselben Hand auszuführen, das Interferenzpotenzial könnte sich also in der TNT-Phase aufgrund dieser gemeinsamen Oberkategorie aufgebaut haben, da jeder Stimulus dieser Phase stets alle Sequenzen der rechten Hand aktivierte. Weitere Studien könnten die Interferenzabhängigkeit motorischen unterdrückungsinduzierten Vergessens eventuell belegen, indem wir analog zum zweiten Artikel dieser Dissertation die TNT-Sequenzen in einer anderen Bedingung mit verschiedenen Händen ausführen liessen.

In dieser motorischen Adaptation des TNT-Paradigmas haben wir motorisches SIF nachweisen können. Im Artikel 2 dieser Dissertation haben wir ein motorisches Analog zum selektiven gerichteten Vergessen deklarativer Inhalte belegen können, dass sich auch noch als interferenzabhängig (siehe Anderson, 2005) erwies, also eindeutig auf Inhibition als Ursache der Kosten hinwies. Beides zusammen legt Effekte inhibitorischer Kontrollprozesse in verschiedenen Repräsentationssystemen nahe, die zum Vergessen motorischer Langzeit-Inhalte beigetragen haben. Es spricht für das gemeinsame Prinzip zu Grunde liegender Inhibitionsprozesse als ein an der Repräsentation selbst wirkender Kontrollmechanismus, der unabhängig vom Repräsentationssystem über die Gedächtnismodule hinweg wirken kann. Inhibition kann flexibel in den verschiedenen Repräsentationssystemen der Zielinhalte ansetzen.

Vergleicht man die ersten mit den zweiten und dritten korrekt erinnerten Tastendrucke (siehe **Figure 2**, obere Hälfte, Seite 59) zeigt sich, dass nicht das erste Element der Sequenz von der willentlichen Unterdrückung betroffen war. Die ganze Sequenz als eine Einheit litt darunter, der willentlich rekrutierte Inhibitionsmechanismus setzte direkt an der Repräsentation an, nicht an der Assoziation zum Konsonanten.

5.4. Schlussfolgerungen

Im ersten Artikel dieser Dissertation konnten wir eine Kontextabhängigkeit für Erinnerungsleistungen an motorische Repräsentationen bestätigen. In Bedingungen der Kontextbeibehaltung oder des -wechsels verhielten sich unsere vier Bedingungsgruppen so, wie es die Theorie der zwei Gesichter des Gedächtnisabrufs (Bäuml, 2019; Bäuml & Samenieh, 2012a, 2012b; Bäuml & Samenieh, 2010) vorhersagt. Die Kontextwechselbedingung wies erwartungsgemäß als einzige einen selbstpropagierenden Verlauf auf, die ersten und zweiten acht erinnerten Sequenzen unterschieden sich in ihrer Erinnerungsgenauigkeit nicht signifikant voneinander. In den drei anderen Bedingungen, die wir als Kontextbeibehaltung verstanden haben, fiel die Erinnerungsgenauigkeit stattdessen signifikant von den ersten auf die zweiten acht erinnerten Sequenzen ab, sie zeigte einen selbstlimitierenden Verlauf. Motorische Repräsentationen wurden also kontextabhängig erinnert. Dies spricht dafür, dass die Gedächtnisprozesse Inhibition oder sich ausbreitende Aktivierung (Roediger & Neely, 1982) auch den motorischen Gedächtnisabruf modulieren. Unsere Versuchsergebnisse zeigen, dass kontextuelle Bedingungen entweder Inhibition oder sich ausbreitende Aktivierung ausgelöst haben, so wie es die Theorie der zwei Gesichter des Gedächtnisabrufs vorhersagt. Wir konnten eine Kontextabhängigkeit der Erinnerungsleistung für motorische Gedächtnisrepräsentationen belegen.

Im Versuchsaufbau des zweiten Artikels zum selektiven gerichteten Vergessen motorischer Sequenzen verhielten sich die abschließend erinnerten Sequenzen aber nicht so, wie es der Kontextwechselansatz zum gerichteten Vergessen (Sahakyan & Kelley, 2002) vorhersagt. Hier hatten wir in einer Bedingung ein Interferenzpotenzial zwischen dem zweiten und dritten Satz motorischer Repräsentationen eingebaut, um Inhibition zu ermöglichen. Die Sequenzen wurden abschließend so erinnert, wie es die allgemeine Theorie des inhibitorischen Erklärungsmodells zum gerichteten Vergessen (Anderson, 2005; Anderson & Hanslmayr, 2014; Bäuml et al., 2008; Geiselman et al., 1983; Hanslmayr et al., 2012) erwartet. Nur wenn ein Interferenzpotenzial zwischen dem zu vergessenden und dem nachfolgend zu encodierenden Satz bestand, trat ein selektives gerichtetes Vergessen motorischer Repräsentationen auch auf. Dies legt neben anderen Studien (Tempel & Frings, 2013, 2017) nahe, dass das Postulat der Interferenzabhängigkeit der Inhibition (Anderson, 2003, 2005) auch für den motorischen Abruf von Inhalten gilt. Unsere Ergebnisse zur Erinnerung motorischer Sequenzen in Artikel 2 dieser Schrift bestätigten also den inhibitorischen Erklärungsansatz zum (selektiven) gerichteten Vergessen für diese Inhalte. Darüberhinaus kann der Kontextwechselansatz unsere Ergebnismuster in Artikel 2 nicht erklären.

Wenn wir einen Versuchsaufbau implementierten, der Kontexteffekte begünstigte, dann kam es zu einer kontextuellen Erinnerungsabhängigkeit motorischer Repräsentationen (Artikel 1). Ermöglichten wir stattdessen das Zustandekommen von kognitiver Inhibition im adaptierten Paradigma des (selektiven) gerichteten Vergessens motorischer Repräsentationen (Artikel 2), indem wir ein Interferenzpotenzial mit nach dem Vergessen-Signal zu encodierenden Sequenzen aufbauten, so wurden die Sequenzen genau nur in dieser einen Bedingung selektiv vergessen, was für eine kognitive Inhibition dieser motorischen Repräsentationen spricht. Die Anforderungen der Aufgaben im Versuchsaufbau unserer beider Artikel könnten darüber entschieden haben, ob es zu einem Kontexteffekt oder zur kognitiven Inhibition kam. Die Salienz von Kontext oder Inhibition für die jeweilige Aufgabe könnte über den sich einstellenden Effekt entschieden haben. Auch ein Zusammenwirken dieser beiden Faktoren ist theoretisch denkbar. Anderson und Hanslmayr (2014) argumentieren, dass die typischen Instruktionen (in der Listenmethode) zum gerichteten Vergessen einen zeitlichen Kontext definieren, eben etwa "die letzte Liste". Diese breite Zielausrichtung könnte in der Umsetzung relativ einfach realisiert werden, indem eher die Repräsentationen des zeitlichen Kontexts zum Ziel von kognitiver Inhibition werden, als die einzelnen Elemente dieses zeitlichen Kontexts stattdessen. Die gerichtete Vergessen-Instruktion könnte den mentalen Kontextwechsel erreichen, indem einfach nur der gesamte zugehörige temporale Kontext inhibiert wird. Entsprechend postulieren Anderson und Hulbert (2021) Gedächtnis-, Prozess- und Kontextinhibition als drei Faktoren in ihrem Modell des aktiven Vergessens, in dem aktives

Vergessen unser Gedächtnis mit unseren momentan vorherrschenden kognitiven und emotionalen Zielen in Einklang bringt. Anderson und Hulbert (2021) gehen in ihrer Argumentation zum dritten Faktor ihrer Theorie von einem Kontextzwischenspeicher aus, in den alle Elemente eines momentan mental assoziierten Kontexts geladen sind (etwa Liste 1). Nun kann dieser Zwischenspeicher per Inhibition dessen Inhalts entleert und mit neuen Elementen eines anderen Kontexts geladen werden (etwa Liste 2). Der Kontext-zwischenspeicher weist dann also auf einen neuen, anderen Kontext hin, was die per Inhibition aus diesem entladenen Elemente (Liste 1) schwerer bis nicht zugänglich macht, ohne ihre zugrunde liegenden Repräsentationen zu verändern. Der mentale Abrufkontext kann möglicherweise inhibitorisch entladen werden. Kontext und Inhibition müssen also nicht als nur konkurrierende Erklärungen für Gedächtniseffekte aufgefasst werden, man kann beide ebenso als interagierende Faktoren zur Gedächtniskontrolle, zur Organisation momentan verfügbarer Inhalte begreifen. Ein Zusammenwirken beider Faktoren auf ausschließlich inhibitorischem Wirkniveau kann durchaus ebenso gegeben sein.

Im dritten Artikel dieser Dissertation wandten wir uns der willentlich rekrutierten Inhibition in Form einer bewussten Unterdrückung des Abrufs zu. Wir konnten zeigen, dass die mehrfache bewusste Unterdrückung der Ausführung und des Abrufs motorischer Sequenzen deren Zugänglichkeit (im Vergleich zu weder unterdrückten noch geübten Sequenzen) deutlich verlangsamte und deren Ausführung tendenziell verlangsamte, wenn diese Sequenzen sehr gut trainiert worden waren. Geschah dies nur moderat, so verringerte die mehrfache bewusste Unterdrückung der Ausführung und des Abrufs die abschließende Erinnerungsgenauigkeit dieser unterdrückten Sequenzen im Vergleich zu Basisraten-Sequenzen ebenso signifikant wie deren Ausführungsgeschwindigkeit. Motorische Sequenzen können also in ihrer Zugänglichkeit und Ausführung per willentlich motivierter kognitiver Unterdrückung bis hin zum Abriss der Erinnerung an diese Sequenzen beeinflusst werden. Wir konnten darüberhinaus zeigen, dass diese bewusst rekrutierten Unterdrückungsprozesse direkt an der Sequenz wirkten, nicht aber an der Assoziation vom auslösenden Buchstaben-Hinweisreiz zur Sequenz (**Figure 2**, Seite 59, obere Hälfte, *first keypress correct* wurde besser erinnert).

Die in den drei Artikeln dieser Dissertation empirisch belegten motorischen Analoge zu Kontext und Inhibition im deklarativen Gedächtnis legen also ein allgemeingültiges Prinzip der Inhibition als einen ebenso willentlich rekrutierbaren Gedächtnisprozess nahe, der innerhalb verschiedener Repräsentationssysteme modalitätsübergreifend Kontrolle über die jeweiligen Repräsentationen direkt an der davon betroffenen Repräsentation selbst ausüben kann, wenn die Voraussetzungen zur Inhibition (Anderson, 2005) gegeben sind.

6. Quellenangaben

Abrahamse, E., Ruitenberg, M., De Kleine, E., & Verwey, W. (2013). Control of automated behavior: Insights from the discrete sequence production task. *Frontiers in Human Neuroscience, 7*, 82. https://doi.org/10.3389/fnhum.2013.00082

Aguirre, C., Gómez-Ariza, C. J., Andrés, P., Mazzoni, G., & Bajo, M. T. (2017). Exploring mechanisms of selective directed forgetting. *Frontiers in Psychology, 8*(316), 1–15. https://doi.org/10.3389/fpsyg.2017.00316

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. Journal of Memory & Language, 49, 415–445.

Anderson, M. C. (2005). The role of inhibitory control in forgetting unwanted memories: A consideration of three methods. In C. MacLeod, & B. Uttl (Eds.), *Dynamic cognitive processes* (pp. 159–190). Tokyo: Springer-Verlag.

Anderson, M. C., Bjork, R.A., Bjork, E. L. (1994). Remembering can cause forgetting: retrieval dynamics in long-term memory. *J. Exp. Psychol. Learn. Mem. Cogn. 20*:1063–1087. DOI: 10.1037//0278-7393.20.5.1063

Anderson, M. C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Nature, 410*, 366–369. https://doi.org/10.1038/35066572

Anderson, M. C., & Hanslmayr, S. (2014). Neural mechanisms of motivated forgetting. *Trends in Cognitive Sciences, 18(6),* 279-292. https://doi.org/10.1016/j.tics.2014.03.002

Anderson, M. C., & Hulbert, J. C. (2021). Active forgetting: Adaptation of memory by prefrontal control. *Annual Review of Psychology, 72*, 1–36. https://doi.org/10.1146/annurev-psych-072720-094140

Bäuml, K.-H. T. (2019). Context retrieval as a critical component in selective memory retrieval. *Current Directions in Psychological Science, 28*, 177–182. DOI:

https://doi.org/10.1177/0963721419827520

Bäuml, K.-H., Hanslmayr, S., Pastötter, B., & Klimesch, W. (2008). Oscillatory correlates of intentional updating in episodic memory. *Neuroimage, 41*, 596–604. https://doi. org/10.1016/j.neuroimage.2008.02.053

Bäuml, K.-H. T., & Samenieh, A. (2010). The two faces of memory retrieval. *Psychological Science*, *21*, 793–795. doi:10.1177/0956797610370162

Bäuml, K.-H. T., & Samenieh, A. (2012a). Selective memory retrieval can impair and improve retrieval of other memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(2), 488–494. DOI: *https://doi.org/10.1037/a0025683*

Bäuml, K.-H. T., & Samenieh, A. (2012b). Influences of part-list cuing on different forms of Episodic forgetting. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *38*(2), 366–375. DOI:*https://doi.org/10.1037/a0025367*

Bäuml, K.-H. T., & Schlichting, A. (2014). Memory retrieval as a self-propagating process, *Cognition*, *132*(1), 16-21, https://doi.org/10.1016/j.cognition.2014.03.007.

Benjamin, A. S. (2006). The effects of list-method directed forgetting on recognition memory. *Psychonomic Bulletin & Review*, *13*(5), 831-836. https://doi.org/10.3758/BF0319 4005

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Verbal Learning and Verbal Behavior, 9*, 255–268. https://doi. org/10.1016/S0022-5371(70)80059-7

Bjork, E. L., Bjork, R. A., & MacLeod, M. D. (2006). Types and consequences of forgetting: Intended and unintended. In L. G. Nilsson & N. Ohta (Eds.), Levels of processing in human memory (pp. 331–354). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Conway, M. A., Harries, K., Noyes, J., Racsmañy, M., & Frankish, C. R. (2000). The disruption and dissolution of directed forgetting: Inhibitory control of memory.

Journal of Memory and Language, *43*, 409–430. https://doi.org/10.1006/jmla.2000.2706

Freud, S. (1915). Repression. In: Strachey, J. (Ed.), The standard edition of the complete psychological work of Sigmund Freud (1953). 14:141-158. The Hogart Press and the Institute of Psycho-Analysis, London.

Frings, C., Hommel, B., Koch, I., Rothermund, K., Dignath, D., Giesen, C., Kiesel, A., Kunde, W., Mayr, S., Moeller, B., Möller, M., Pfister, R., & Philipp, A. (2020). Binding and retrieval in action control (BRAC). Trends in Cognitive Sciences, 24, 375–387. https://doi.org/10.1016/j.tics.2020.02.004

Geiselman, R. E., Bjork, R. A., & Fishman, D. (1983). Disrupted retrieval in directed forgetting: A link with posthypnotic amnesia. *Journal of Experimental Psychology: General*, *112*(1), 58–72. https://doi.org/10.1037/0096-3445.112.1.58

Godden, D. R., & Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology (1975)*, *66*(3), 325–331. DOI: *https://doi.org/10.1111/j.2044-8295.1975.tb01468.x*

Hanslmayr, S., Volberg, G., Wimber, M., Oehler, N., Staudigl, T., Hartmann, T., et al. (2012). Prefrontally driven down-regulation of neural synchrony mediates goal-directed forgetting. *Journal of Neuroscience*, *32*, 14742–14751. https://doi.org/10.1523/JNEUROSCI.1777-12.2012

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. Behavioral and Brain Sciences, 24, 849–878. doi:10.1017/ S0140525X01000103

Kliegl, O., Pastötter, B., & Bäuml, K.-H. T. (2013). List-method directed forgetting can be selective: Evidence from the 3-list and the 2-list tasks. *Memory & Cognition*, *41*, 452–464. https://doi.org/10.3758/s13421-012-0264-7

Laub, R., & Frings, C. (2018). Distractor-based Retrieval in Action Control: The Influence of

Encoding Specificity. *Psychological Research* (pp. 1–9). DOI: *https://doi.org/10.1007/s00426-018-1082-8*

McGeoch, J. A. (1942). *The Psychology of Human Learning: An Introduction*. New York: Longmans.

MacLeod, C. (1989). Directed forgetting affects both direct and indirect tests of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(1), 13–21. https://doi.org/10.1037/0278-7393.15.1.13

MacLeod, C. (1998). Directed forgetting. In J. M. Golding, & C. MacLeod (Eds.), *Intentional forgetting: Interdisciplinary approaches* (pp. 1–57). Hillsdale, NJ: Erlbaum.

MacLeod, C.M., 2007. The concept of inhibition in cognition. In: MacLeod, David S., Gorfein, Colin M. (Eds.), Inhibition in Cognition. American Psychological Association.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., Bibi, U. (2003). In opposition to inhibition. *Psychology of Learning and Motivation, 43*, 163–214.

Müller, G. E., Pilzecker, A. (1900). Experimentelle Beiträge zur Lehre vom Gedächtnis. Experimental contributions to the science of memory. Z Psychol Ergänzungsband 1: 1–300.

Pastötter, B., & Bäuml, K.-H. (2007). The crucial role of postcue encoding in directed forgetting and context-dependent forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(5), 977–982. https://doi.org/10.1037/0278-7393.33.5.977

Pastötter, B., & Bäuml, K. H. (2010). Amount of postcue encoding predicts amount of Directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(1), 54-65. https://doi.org/10.1037/a0017406

Pastötter, B., Tempel, T., & Bäuml, K. H. T. (2017). Long-term memory updating: The reset-of-encoding hypothesis in list-method directed forgetting. *Frontiers in Psychology, 8*, 2076. https://doi.org/10.3389/fpsyg.2017.02076

Roediger, H.L. (1973). Inhibition in recall from cueing with recall targets. *Journal of Verbal Learning and Verbal Behavior, 12*(6), 644-657. https://doi.org/10.1016/S0022-5371(73)80044-1.

Roediger, H.L. (1974). Inhibiting effects of recall. *Memory & Cognition* 2, 261–269. https://doi.org/10.3758/BF03208993

Roediger, H. L., III, & Neely, J. H. (1982). Retrieval blocks in episodic and semantic memory. *Canadian Journal of Psychology, 36*, 213–242.

Ruitenberg, M. F. L., De Kleine, E., Van der Lubbe, R. H. J., Verwey, W. B., & Abrahamse, E. L. (2012). Context-dependent motor skill and the role of practice. *Psychological Research*, *76*, 812–820. DOI:*https://doi.org/10.1007/s00426-011-0388-6*

Sahakyan, L. (2004). Destructive effects of “forget” instructions. *Psychonomic Bulletin & Review, 11*, 555–559. https://doi.org/10.3758/BF03196610

Sahakyan, L., & Delaney, P. F. (2003). Can encoding differences explain the benefits of directed forgetting in the list method paradigm? *Journal of Memory and Language, 48*(1), 195-206. https://doi.org/10.1016/S0749-596X(02)00524-7

Sahakyan, L., & Kelley, C. M. (2002). A contextual change account of the directed forgetting effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(6), 1064–1072. https://doi.org/10.1037/0278-7393.28.6.1064

Slamecka, N. J. (1968). An examination of trace storage in free recall. *Journal of Experimental Psychology*, *76*(4), 504-513. DOI: 10.1037/h0025695

Smith, A. D. Output interference and organized recall from long-term memory. Journal of Verbal Learning & Verbal Behavior, 1971, 10, 400–408. https://doi.org/10.1016/S0022-5371(71)80039-7

Smith, S. M., Glenberg, A., & Bjork, R. A. (1978). Environmental context and human memory. *Memory & Cognition*, *6,* 342–353. DOI:*https://doi.org/10.3758/BF03197465*

Tempel, T., Aslan, A., & Frings, C. (2016). Competition dependence of retrieval induced forgetting in motor memory. *Memory & Cognition, 44*(4), 671–680. https://doi.org/10.3758/s13421-015-0578-3

Tempel, T., & Frings, C. (2013). Resolving interference between body movements: Retrieval-induced forgetting of motor sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39,* 1152–1161. https://doi.org/10.1037/ a0030336

Tempel, T., & Frings, C. (2014a). Forgetting motor programmes: Retrieval dynamics in procedural memory. *Memory, 22*, 1116–1125. https://doi.org/10.1080/09658211.2013.871293

Tempel, T., & Frings, C. (2014b). Interference within hands: Retrieval-induced forgetting of left and right hand movements. *Acta Psychologica*, *148,* 1–5. https://doi.org/10.1016/j.actpsy.2014. 01.003

Tempel, T., & Frings, C. (2015). Categorization by movement direction: Retrieval induced forgetting of motor sequences grouped by motion features. *The Quarterly Journal of Experimental Psychology, 68,* 473–486. https://doi.org/10.1080/17470218.2014.945098

Tempel, T., & Frings, C. (2016). Directed forgetting benefits motor sequence encoding. *Memory & Cognition*, *44*, 413–419. *https://doi.org/10.1080/09658211.2015.1059858*

Tempel, T., & Frings, C. (2017). Retrieval-induced forgetting is retrieval-modality specific: Evidence from motor memory. *Cognition, 162*(2017), 143–152. https://doi.org/10.1016/j.cognition.2017.02.005

Underwood, B. J. (1957). Interference and forgetting. *Psychological Review, 64* (1),49-60.

Wright, D. L., & Shea, C. H. (1991). Contextual dependencies in motor skills. *Memory & Cognition*, *19,* 361–370. DOI: *https://doi.org/10.3758/BF03197140*

7. Schriftliche Erklärung

Hiermit erkläre ich, dass:

1. die vorliegende Arbeit von mir erstellt und basierend auf meiner Arbeit entstanden ist.

2. nur die angegebenen Quellen und Hilfsmittel benutzt wurden.

3. wörtlich oder sinngemäß aus anderen Werken übernommene Inhalte als solche kenntlich gemacht wurden und

4. die Arbeit oder Teile davon bislang nicht an einer Hochschule des In- und Auslands als Bestandteil einer Promotionsleistung vorgelegt wurden.

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