EEG Korrelate und Gedächtnisleistungen bei spontanen fazialen Selbstberührungen

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Abkürzungsverzeichnis

COVID-19	Coronavirus-Pandemie 2019
sFST	spontane faziale Selbstberührungen
EEG	Elektroenzephalographie
HT	Personen, die häufig sFST ausführen
LT	Personen, die selten sFST ausführen
FPI-R	Freiburger Persönlichkeitsinventar

1. Einführung

Die Beschreibung spontaner Berührungen des eigenen Körpers findet sich bereits in der psychologischen Forschungsliteratur der 1930er Jahre (Krout, 1935). Das spontane Berühren des eigenen Gesichts tritt Studien zufolge häufiger auf als das spontane Berühren anderer Körperteile (Butzen et al., 2005; Ekman & Friesen, 1972; Harrigan, 1985). Trotz jahrzehntelanger Forschung sowie aktueller Präsenz des Themas im Zusammenhang mit der COVID-19-Pandemie, sind zentrale Fragen zu Auslösemechanismen und psychophysiologischen Funktionen von spontanen fazialen Selbstberührungen bislang unbeantwortet. Die vorliegende Dissertation liefert anhand neurophysiologischer sowie behavioraler Daten neue Erkenntnisse zu Funktionen von spontanen fazialen Selbstberührungen und trägt damit zur Weiterentwicklung der Theorie dieses Verhaltens bei.

1.1. Spontane faziale Selbstberührungen

1.1.1. Definition

Das spontane Berühren des eigenen Gesichts (spontaneous facial self-touch, sFST) ist ein alltägliches Verhalten, das von allen Menschen – unabhängig von Geschlecht, Alter oder Herkunft – ausgeführt wird (Spille et al., 2021). Der Terminus „spontan“ bedeutet, dass die ausführende Person keine bewusste Aufmerksamkeit auf die Initiierung oder Ausführung dieses Verhaltens richtet und die Genauigkeit der Erinnerung an dieses Verhalten schlecht ist (Ekman & Friesen, 1969; Hall et al., 2007; Harrigan et al., 1987). Zudem unterliegen sFST keiner offensichtlichen Motivation (z.B. Schweiß aus dem Gesicht wischen) und sie dienen keinen kommunikativen oder sozialen Funktionen (z.B. einer Person „den Vogel zeigen“) (Butzen et al., 2005; Harrigan et al., 1991; Heaven et al., 2002). Somit unterscheiden sich sFST von „aktiven“ Selbstberührungen, die beispielsweise auf Aufforderung ausgeführt werden oder einem ersichtlichen Zweck dienen (z.B. eine Haarsträhne aus dem Gesicht streichen).

Hochrechnungen zufolge werden sFST 400-800 Mal an einem durchschnittlichen 16 Stunden Tag ausgeführt (Spille et al., 2021). Dabei weisen Studienbefunde darauf hin, dass es eine große interindividuelle Streuung dieses Verhaltens gibt (Elder et al., 2014; Kwok et al., 2015; Stefaniak et al., 2021). Spontane faziale Gesichtsberührungen haben eine mittlere Dauer von weniger als 3 – 6 Sekunden und unterscheiden sich somit von lang andauernden fazialen Selbstberührungen von bis zu mehreren Minuten (Spille et al., 2021; Zhang et al., 2020). Am häufigsten sind sFST auf die Mittellinie des Gesichts (Kinn, Mund, Nase) gerichtet (Rahman et al., 2020; Spille et al., 2021). Dabei wird das Gesicht mit einer oder beiden Händen gleichzeitig berührt. Studien zeigen, dass Personen aller Altersstufen sFST ausführen: Föten (Reissland et al., 2015a; Reissland et al., 2015b), Neugeborene und Säuglinge (DiMercurio et al., 2018; Konishi et al., 1997; Rochat & Hespos, 1997), Kleinkinder (D'Alessio & Zazzetta, 1986) sowie Erwachsene (Goldberg & Rosenthal, 1986; Hatta & Dimond, 1984; Knöfler & Imhof, 2007). Zudem sind sFST nicht nur Gegenstand der Humanforschung, sondern werden auch innerhalb der Primatenforschung untersucht (Dimond & Harries, 1984; Suarez & Gallup, 1986).

1.1.2. Forschungsstand

1.1.2.1. Auslösemechanismen

Bisherige Forschungsbefunde deuten darauf hin, dass sFST besonders häufig dann ausgeführt werden, wenn negative Emotionen wie Angst, Anspannung, Unbehagen oder Unsicherheit evoziert werden (D'Alessio & Zazzetta, 1986; Goldberg & Rosenthal, 1986; Knöfler & Imhof, 2007; Moszkowski & Stack, 2007). Befunde zu sFST stammen insbesondere aus Beobachtungsstudien, in denen das nonverbale Verhalten von Versuchsteilnehmenden während sozialer Interaktion untersucht wurden. Harrigan (1985) untersuchte Ärzt:innen und Patient:innen während Gesprächen über medizinische Probleme und psychosoziale Aspekte, die mit diesen Problemen einhergingen. Der Autor fand heraus, dass sFST sowohl von Ärzt:innen als auch von Patient:innen am häufigsten ausgeführt wurden, wenn die Patient:innen über ihre Krankheit und ihre diesbezüglichen Gefühle sprachen. In einer anderen Studie wurde das sFST-Verhalten von Säuglingen in Abhängigkeit von der Verfügbarkeit der Mutter während eines Still-Face Experiments untersucht (Moszkowski & Stack, 2007). Das Experiment bestand aus zwei normalen Interaktionsphasen, separiert durch eine Phase, in der die Mütter ihre Kinder anstarrten, während sie ein ausdrucksloses Gesicht bewahrten und ihre Kinder weder ansprachen noch berührten. Die sFST-Häufigkeit der Säuglinge vervierfachte sich während der zweiminütigen Phase mit starrem Gesicht im Vergleich zu den normalen Interaktionsphasen (Moszkowski & Stack, 2007).

Spontane faziale Gesichtsberührungen treten jedoch nicht nur während sozialer Interaktion auf, sondern sind auch in Abwesenheit anderer Personen zu beobachten. Dabei weisen Studien darauf hin, dass sFST vor allem unter erhöhter kognitiver Belastung auftreten.

So beobachteten Studien einen Anstieg der Häufigkeit von sFST wenn Versuchspersonen Aufgaben mit zunehmender Komplexität und steigenden Aufmerksamkeitsanforderungen bewältigen mussten (Barroso et al., 1978; Barroso & Feld, 1986). Barroso und Kollegen fanden heraus, dass eine höhere Anzahl von sFST mit besseren Leistungen bei einer Gedächtnisaufgabe und einer Aufmerksamkeitsaufgabe (Stroop-Test) verbunden war (Barroso et al., 1980). Weitere Studien fanden eine höhere Rate von sFST, wenn ablenkende auditive Reize während einer verzögerten Gedächtnisaufgabe präsentiert wurden (Grunwald et al., 2014; Mueller et al., 2019). Ein hochfrequentes sFST-Verhalten wurde darüber hinaus bei Studierenden beobachtet, die in einem Büro arbeiteten (M = 36,5 sFST pro Stunde; Zhang et al., 2020) sowie bei Studienteilnehmenden, die Büroarbeit (z.B. Arbeiten an einem Laptop, Lesen, Schreiben) verrichten mussten (M = 15,67 sFST pro Stunde; Nicas & Best, 2008).

1.1.2.2. Erklärungsmodelle

Theoretische Modelle, die das Auftreten von sFST erklären, sind hauptsächlich aus Beobachtungsstudien abgeleitet worden. In einigen Studien wurde das sFST-Verhalten als körperliche Manifestation zugrundeliegender negativer Emotionen interpretiert (Goldberg & Rosenthal, 1986; Harrigan, 1985; Knöfler & Imhof, 2007). Dieser Annahme folgend gelten sFST als Indikator für negative Emotionen, die von Individuen nicht bewusst offenbart, sondern in Form von sFST ausgedrückt werden.

Andere Autoren beschreiben sFST nicht als körperliche Manifestation zugrundeliegender Emotionen, sondern als körpereigene Regulationsmechanismen. Faziale Gesichtsberührungen werden demzufolge in emotional belastenden Situationen ausgeführt, um die eigenen affektiven Zustände zu regulieren und das emotionale Gleichgewicht wiederherzustellen (D'Alessio & Zazzetta, 1986; Moszkowski & Stack, 2007; Mueller et al., 2019). Auch in der Primatenforschung werden selbstberuhigende Funktionen von sFST diskutiert (Bard et al., 1990).

Als Folge der Beobachtung, dass die sFST-Frequenz mit steigenden Gedächtnis- und Aufmerksamkeitsforderungen zunimmt, wurden sFST darüber hinaus kognitionsregulierende Funktionen zugeschrieben. Es wird angenommen, dass das Ausführen von sFST zu einer stärkeren Fokussierung der Aufmerksamkeit führt und somit der Koordination komplexer kognitiver Prozesse dient (Barroso et al., 1978; Barroso et al., 1980; Mueller et al., 2019).

Neben situativen Faktoren wurden auch Persönlichkeitsmerkmale als Determinanten für das Auftreten von sFST herangezogen. In einer früheren Studie wurde der Zusammenhang zwischen nonverbalem Kommunikationsverhalten und den beiden Persönlichkeitsmerkmalen Extraversion und Neurotizismus untersucht (Campbell & Rushton, 1978). Die Autor:innen fanden heraus, dass Selbstberührungen positiv mit der Bewertung von Neurotizismus zusammenhingen, wenn der Neurotizismus durch Lehrkräfte der bewerteten Person bewertet wurde, während der selbstberichtete Neurotizismus nicht mit dem Berührungsverhalten zusammenhing. Andere Forschungsergebnisse, welche die Auswirkungen des sFST-Verhaltens auf andere Personen beobachteten, fanden heraus, dass Personen, die sFST ausführten, als aufgeschlossener, dominanter, ausdrucksstärker und interessierter wahrgenommen wurden als Personen, die keine sFST ausführten (Harrigan et al., 1986b; Harrigan et al., 1986a). Es ist jedoch fraglich, ob diese wahrgenommenen Eigenschaften sich tatsächlich in manifesten Persönlichkeitsmerkmalen widerspiegeln und ob diese mit der Häufigkeit des sFST-Verhaltens zusammenhängen. Jüngst veröffentlichte Forschungsergebnisse weisen auf einen positiven Zusammenhang zwischen der Persönlichkeitseigenschaft Angst und der Häufigkeit und Dauer von sFST hin (Carrillo-Diaz et al., 2021a; Carrillo-Díaz et al., 2021b).

1.1.2.3. Neurophysiologie der sFST

Die dargestellten Erklärungsmodelle zu Funktionen von sFST beruhen ausschließlich auf Verhaltensdaten, welche in Beobachtungsstudien gewonnen wurden. In der gesamten sFST Forschung gab es bis 2021 nur eine Studie, in der die Funktionen von sFST anhand neurophysiologischer Parameter mittels Elektroenzephalographie (EEG) untersucht wurden. Grunwald *et al.* (2014) analysierten bei 14 Versuchspersonen frequenzbandspezifische kortikale Leistungsänderungen des EEG vor und nach sFST. Die Teilnehmenden der Studie absolvierten eine verzögerte Gedächtnisaufgabe mit komplexen haptischen Reliefstimuli, während auditive Distraktoren (z.B. Babygeschrei, Explosion, Sirene) präsentiert wurden. Während der Behaltensphasen führten die Versuchspersonen signifikant häufiger sFST aus, als während der übrigen Phasen des Experiments. Die Autor:innen beobachteten charakteristische spektrale Leistungsänderungen im Theta- und Gamma-Band, die darauf hindeuten, dass sFST hirnregulatorische Funktionen erfüllen: Kurz vor sFST sank die spektrale Leistung in beiden Frequenzbändern signifikant ab, was den Autor:innen zufolge auf eine Beeinträchtigung der Aufrechterhaltung von Arbeitsgedächtnisinformationen hinweist. Der signifikante spektrale Anstieg kurz nach sFST weist den Autor:innen zufolge auf eine erfolgreiche Wiederherstellung der Arbeitsgedächtnisinhalte hin. Zudem interpretierten die Autor:innen die Veränderungen im Theta-Band im Zusammenhang mit emotionalen

Regulationsprozessen als Reaktion auf die aversiven auditiven Distraktoren. Weiterhin wurden in der Studie von Grunwald *et al.* (2014) spektrale Leistungsänderungen vor und nach instruierten fazialen Selbstberührungen analysiert, die nach Aufforderung der Versuchsleitung in einer Referenzsituation ohne zusätzliche kognitive Anforderungen ausgeführt werden mussten. Es wurden in keinem Frequenzband signifikante spektrale Leistungsänderungen vor oder nach instruierten fazialen Selbstberührungen festgestellt. Durch die Studienergebnisse von Grunwald *et al.* (2014) konnte somit erstmals gezeigt werden, dass sFST mit spezifischen Veränderungen der elektrischen Hirnaktivität einhergehen, die auf eine Beteiligung von sFST an regulativen emotionalen sowie kognitiven Prozessen hindeuten.

1.1.2.4. Infektionsübertragung durch sFST

Zuletzt rückten sFST vermehrt in den Fokus des Forschungsinteresses, da das spontane Berühren des eigenen Gesichts mit dem Risiko der Infektionsübertragung verbunden ist. Wenn die Hände mit kontaminierten Oberflächen in Kontakt kommen und anschließend sFST ausgeführt werden, können Pathogene auf die eigenen Gesichtsschleimhäute (Mund, Nase, Augen) übertragen werden (Rusin et al., 2002; Spencer et al., 2021; Zhao et al., 2012). Seit dem Beginn der COVID-19-Pandemie stieg die Anzahl an Publikationen, die sich mit der Notwendigkeit der Reduzierung von Gesichtsberührungen befasste. Dabei wurden zum einen physische Barrieren, die den Kontakt zwischen Finger- und Gesichtshaut verhindern, untersucht. In einer Studie führten die Versuchspersonen weniger sFST durch, wenn sie Latexhandschuhe trugen im Vergleich zu einer Kontrollsituation ohne Handschuhe (Carrillo-Díaz et al., 2021b). In einer anderen Studie wurden Haftbänder verwendet, um die Ausführung der Armbeugung, die der sFST vorausgeht, zu verhindern. Das Abkleben der Streckseite des Ellenbogens führte jedoch nicht zu einer anhaltenden Verhinderung des sFST-Verhaltens (Senthilkumaran et al., 2020). Der Einfluss von Mund-Nasen-Schutzmasken auf das sFST-Verhalten wird in der Forschung derzeit kontrovers diskutiert. Einige Autor:innen fanden eine negative Korrelation zwischen dem Tragen einer Maske und der sFST-Häufigkeit (Chen et al., 2020; Shiraly et al., 2020). Im Gegensatz dazu berichteten andere Autor:innen eine erhöhte Tendenz das Gesicht während des Tragens einer Maske zu berühren (Guellich et al., 2021), insbesondere wenn die Maske von der Nase rutschte und die Position der Maske infolgedessen korrigiert werden musste (Lucas et al., 2020). Ein anderes Forscherteam beobachtete jedoch keine Unterschiede in der sFST-Frequenz in Abhängigkeit vom Tragen einer Maske (Tao et al., 2020).

Mehrere Forschergruppen haben tragbare Geräte zur Verhinderung von sFST entwickelt, die z. B. eine vibrotaktile oder akustische Rückmeldung geben und ein Warnsignal senden, wenn sich die Hand dem Gesicht nähert (Bai et al., 2021; D'Aurizio et al., 2020; Michelin et al., 2021). Es fehlen jedoch Daten zur langfristigen Wirksamkeit solcher Maßnahmen.

1.2. Ableitung der Forschungsfragen

1.2.1. Studie 1

Obwohl seit Jahrzenten zu Auftretenshäufigkeiten und –bedingungen von sFST geforscht wird und sFST zuletzt aufgrund des Risikos der Infektionsübertragung zunehmend in den Fokus der Forschung gerückt sind, bleiben zentrale Fragen zu Funktionsweisen von sFST bislang unbeantwortet. Dies ist insbesondere auf den Mangel an kontrollierten, experimentellen Studien zurückzuführen (Spille et al., 2021). Außer der Studie von Grunwald *et al.* (2014) gab es bis dato keine neurophysiologischen Studien zum Phänomen der sFST. Aus diesem Grund, und um die theoretischen Annahmen bezüglich der regulatorischen Funktionen von sFST zu überprüfen, war es das Ziel von Studie 1 (Spille et al., 2022a), die Ergebnisse von Grunwald *et al.* (2014) zu replizieren. Anhand einer größeren Stichprobe (N = 60) wurde untersucht, ob sFST mit spezifischen Veränderungen der elektrischen Hirnaktivitäten verbunden sind, die auf die vermutete Beteiligung von sFST an der Regulation von Aufmerksamkeits-, Emotions- und Arbeitsgedächtnisprozessen hinweisen. Die Methoden der Studie von Grunwald *et al.* (2014) wurden so genau wie möglich reproduziert. Um die Generalisierbarkeit der Ergebnisse jedoch zu erhöhen und methodische Mängel der Vorgängerstudie zu beheben, wurden Modifikationen in Bezug auf methodische und analytische Verfahren vorgenommen. Eine methodische Weiterentwicklung gegenüber der Vorgängerstudie von Grunwald *et al.* (2014) bestand in der Applikation triaxialer Beschleunigungssensoren an den Unterarmen der Versuchspersonen. Dadurch konnte erstmals eine genauere Aufzeichnung der Bewegungsstruktur der sFST und somit eine präzise Analyse der verschiedenen Phasen einer sFST (Bewegung der Hand hin zum Gesicht, Hautkontaktphase zwischen Finger und Gesicht, Bewegung der Hand weg vom Gesicht) durchgeführt werden. Es konnten somit nicht nur dreisekündige Abschnitte vor Beginn und nach Beendigung der sFST analysiert werden, wie es in der Vorgängerstudie umgesetzt wurde. Stattdessen konnten erstmals neurophysiologische Veränderungen *während* der Ausführung von sFST untersucht werden, indem die ersten 500 Millisekunden zu Beginn und die letzten

500 Millisekunden am Ende der Hautkontaktphase segmentiert und analysiert wurden. Darüber hinaus wurde in der Studie von Grunwald *et al.* (2014) keine Analyse des niederfrequenten Delta-Bands durchgeführt. Da Aktivitäten im Delta-Band jedoch im Zusammenhang mit kognitiven und emotionalen Prozessen diskutiert wurden (Güntekin & Başar, 2016; Knyazev, 2012), wurden in der hier beschriebenen Studie spektrale Leistungsänderungen im Delta-Band berechnet. Da die neurophysiologische sFST-Forschung noch am Anfang ihrer Entwicklung steht, ist ein explorativer Ansatz entscheidend, um keine wesentlichen Befunde zu übersehen, die einen Beitrag zur Weiterentwicklung der sFST-Theorie leisten könnten.

Die Daten für die vorliegende Studie 1 (Spille et al., 2022a) wurden in einem Experiment erhoben, in dem die Ausführung von sFST während einer verzögerten Arbeitsgedächtnisaufgabe mit komplexen haptischen Reliefstimuli getriggert wurde. Das Experiment bestand aus zwei Experimentalblöcken, in denen die Teilnehmenden jeweils zwei haptische Stimuli ertasten, diese für eine Behaltensphase von 14 Minuten im Gedächtnis aufrechterhalten und anschließend auf ein Blatt Papier aufzeichnen mussten. Während der Behaltensphase wurden auditive Distraktoren (z.B. Babygeschrei, Explosion, Sirene) dargeboten. In die Analyse wurden solche sFST aufgenommen, die während der Behaltensphase ausgeführt wurden. Eine schematische Darstellung des Versuchsablaufs ist in Abbildung 1 nachgebildet.

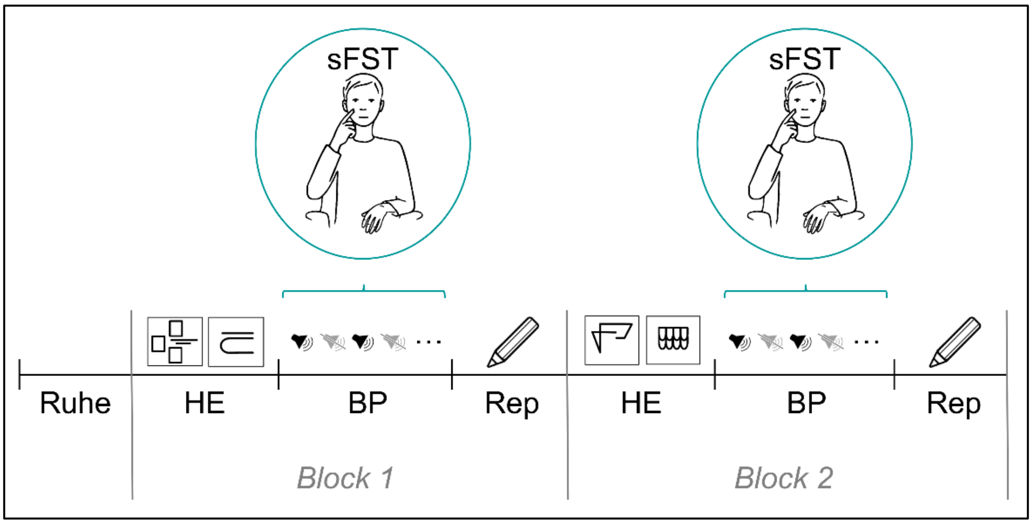

Abbildung 1. Schematische Darstellung des Experimentalablaufs (Studie 1). Nach einer dreiminütigen Ruhephase (baseline, geöffnete Augen), mussten zwei Reliefstimuli haptisch exploriert (HE) und für eine Dauer von 14 Minuten im Gedächtnis aufrechterhalten werden (Behaltensphase, BP). Während der BP wurden abwechselnd 40 auditive Distraktoren und 40 geräuschfreie Phasen dargeboten. Spontane faziale Selbstberührungen (sFST), die während der BP auftraten, wurden in die weiterführende Analyse aufgenommen. Nach der BP mussten die Versuchspersonen die erinnerten Reliefstimuli zeichnerisch reproduzieren (Rep). Nach dem ersten Experimentalblock (Block 1) wurde die Prozedur mit zwei anderen Reliefstimuli wiederholt (Block 2).

Um die Ergebnisse von Grunwald *et al.* (2014) zu replizieren, wurden frequenzbandspezifische Leistungsunterschiede in den Frequenzbändern Delta (0,5 – 4,0 Hz), Theta (4,0 – 8,0 Hz), Alpha (8,0 – 13,0 Hz), Beta (13,0 – 24,0 Hz) und Gamma (24,0 – 49,0 Hz) berechnet, indem die mittleren absoluten Spektralleistungen zwischen aufeinanderfolgenden Ereignissen des Experiments verglichen wurden. Es wurden spektrale Leistungsänderungen zwischen den Ereignissen sowie vor, während und nach sFST erwartet.

1.2.2. Studie 2

Obwohl jeder Mensch sFST ausführt, zeigen Studien, dass es eine starke Streuung des individuellen sFST-Verhaltens gibt (Elder et al., 2014; Kwok et al., 2015; Stefaniak et al., 2021). Bislang ist die Frage, wieso einige Personen besonders häufig sFST ausführen (high self-touching individuals, HT), andere Personen hingegen weniger häufig (low self-touching individuals, LT), ungeklärt. Ralph *et al.* (2021), die das sFST-Verhalten während des Autofahrens untersuchten, betonten erstmals die hohe interindividuelle Variabilität des sFST-Verhaltens. Sie diskutierten, dass den individuellen Unterschieden möglicherweise

Persönlichkeitsfaktoren zugrunde liegen könnten und forderten eine intensive Erforschung der möglichen Determinanten des sFST-Verhaltens.

Da die Erkenntnisse über den Zusammenhang zwischen Persönlichkeitsmerkmalen und sFST-Verhalten bisher begrenzt sind, wurde im ersten Teilziel von Studie 2 (Spille et al., 2022b) untersucht, ob es Persönlichkeitsmerkmale gibt, die mit individuellem sFST-Verhalten assoziiert sind. Hierzu wurde erstmals in der experimentellen sFST-Forschung zwischen den Gruppen der HT und der LT unterschieden. Zur Erfassung von Persönlichkeitsmerkmalen wurde das Freiburger Persönlichkeitsinventar (FPI-R; Fahrenberg et al., 2001) gewählt, ein deutschsprachiges multidimensionales Persönlichkeitsinventar, das Persönlichkeitsmerkmale auf 12 verschiedenen Skalen misst. Es wurde erwartet, dass sich HT und LT auf den Skalen des FPI-R signifikant voneinander unterscheiden.

Im zweiten Teilziel von Studie 2 (Spille et al., 2022b) wurden Konsequenzen der Verhinderung von sFST untersucht. Die im Rahmen der COVID-19-Pandemie entstandenen Forschungsarbeiten zu Möglichkeiten der Verhinderung von sFST brachten diverse Ansätze hervor, um sFST zu unterdrücken, ohne dabei mögliche Konsequenzen dieser Verhinderung zu thematisieren. Der Annahme folgend, dass sFST der Regulation von Aufmerksamkeits- und Gedächtnisprozessen dienen, hat die Verhinderung von sFST möglicherweise negative Konsequenzen in Bezug auf kognitive Prozesse wie Aufmerksamkeitsfokussierung oder Aufrechterhaltung von Informationen im Arbeitsgedächtnis. Insbesondere die kognitive Leistung von HT könnte durch die Unterdrückung von sFST negativ beeinflusst werden, da diese Personen nicht auf ihr natürliches Verhaltensrepertoire zurückgreifen können. Um diese Hypothese zu prüfen, wurde das Studiendesign aus Studie 1 angewandt und um zwei Experimentalblöcke erweitert (s. Abbildung 2). In den beiden zusätzlichen Experimentalblöcken konnten die Versuchspersonen während der Behaltensphase keine sFST ausführen („immobilisierte Hände“), während sie sich in den beiden anderen Experimentalblöcken frei bewegen konnten („freie Hände“) und somit die Ausführung von sFST nicht beeinflusst war. In der Bedingung „immobilisierte Hände“ wurden die Finger der Versuchspersonen in einer Haltevorrichtung locker in einer Klettverschlussschlaufe fixiert. Als Maß für die Gedächtnisleistung diente die durch drei unabhängige Rater bewertete Reproduktionsleistung der Reliefstimuli. Für die Gruppe der HT wurde erwartet, dass die Gedächtnisleistung in der Bedingung „immobilisierte Hände“ schlechter ist, als in der Bedingung „freie Hände“. Für die Gruppe der LT wurde erwartet, dass es keinen Unterschied in der Gedächtnisleistung zwischen den beiden Bedingungen gibt.

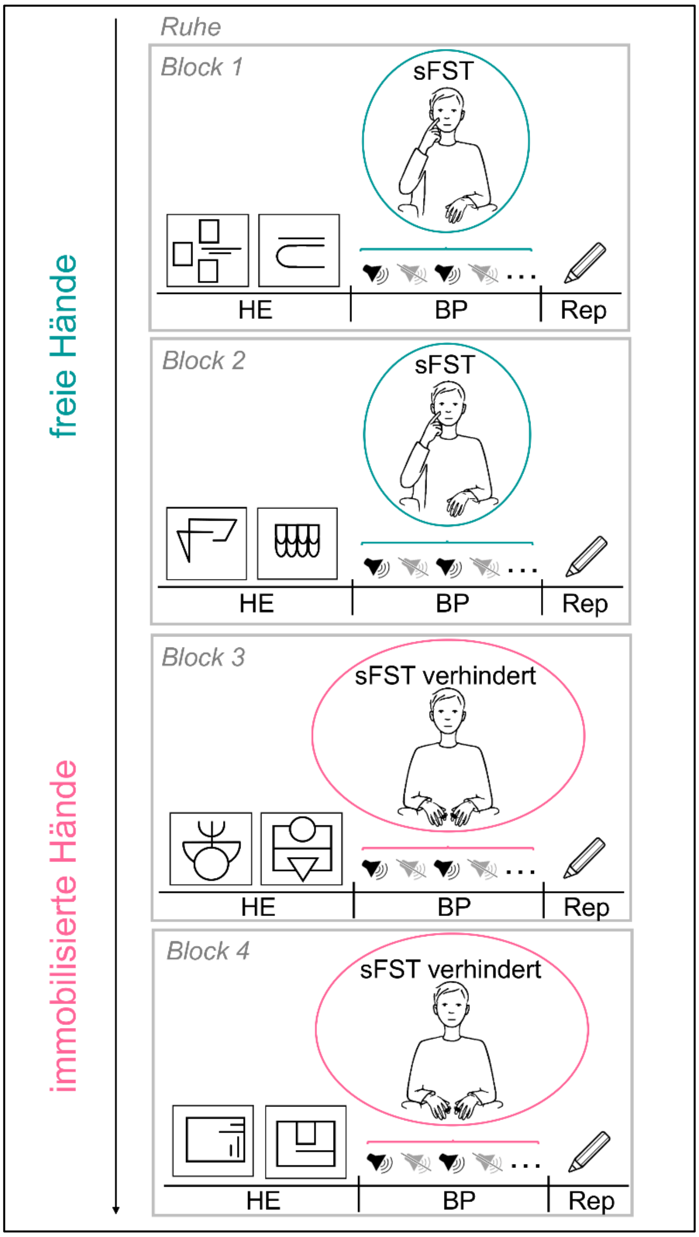

Abbildung 2. Schematische Darstellung des Experimentalablaufs (Studie 2). Nach einer dreiminütigen Ruhephase (baseline, geöffnete Augen), mussten zwei Reliefstimuli haptisch exploriert (HE) und für eine Dauer von 14 Minuten aufrechterhalten werden (Behaltensphase, BP). Während der BP wurden abwechselnd 40 auditive Distraktoren und 40 geräuschfreie Phasen dargeboten. Nach der BP mussten die Versuchspersonen die erinnerten Reliefstimuli zeichnerisch reproduzieren (Rep). Nach dem ersten Block (Block 1) wurde das Verfahren ein zweites Mal wiederholt (Block 2). In der Bedingung „freie Hände" (Block 1 & 2) konnten die Versuchspersonen ungehindert spontane faziale Selbstberührungen (sFST) während der BP ausführen. In der Bedingung „immobilisierte Hände" (Block 3 & 4) waren die Finger der Versuchspersonen während der BP locker fixiert, sodass keine sFST ausgeführt werden konnten. Die Reihenfolge der Bedingungen wurde randomisiert. Jeder Block enthielt zwei verschiedene Reliefstimuli. Die Stimuli wurden zwischen den Blöcken randomisiert.

2. Publikationsmanuskripte

Spille, J. L., Müller, S. M., Martin, S. & Grunwald, M. (2022a).
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RESEARCH ARTICLE

Cognitive and emotional regulation processes of spontaneous facial self-touch are activated in the first milliseconds of touch: Replication of previous EEG findings and further insights

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Abstract

Spontaneously touching one's own face (sFST) is an everyday behavior that occurs in people of all ages, worldwide. It is—as opposed to actively touching the own face—performed without directing one's attention to the action, and it serves neither instrumental (scratching, nose picking) nor communicative purposes. These sFST have been discussed in the context of self-regulation, emotional homeostasis, working memory processes, and attention focus. Even though self-touch research dates back decades, neuroimaging studies of this spontaneous behavior are basically nonexistent. To date, there is only one electroencephalography study that analyzed spectral power changes before and after sFST in 14 participants. The present study replicates the previous study on a larger sample. Sixty participants completed a delayed memory task of complex haptic relief stimuli while distracting sounds were played. During the retention interval 44 of the participants exhibited spontaneous face touch. Spectral power analyses corroborated the results of the replicated study. Decreased power shortly before sFST and increased power right after sFST indicated an involvement of regulation of attentional, emotional, and working memory processes. Additional analyses of spectral power changes during the skin contact phase of sFST revealed that significant neurophysiological changes do not occur while skin contact is in progress but at the beginning of sFST (movement toward face and initial skin contact). The present findings clearly illustrate the complexity of sFST and that the specific trigger mechanisms and functions of this spontaneous behavior need to be further investigated in controlled, experimental studies.

Keywords Face touch · Spectral EEG power · Attention · Working memory · Emotion

Introduction

Spontaneously touching the own face with one or both hands (sFST) is a common everyday behavior performed by people of all ages: fetuses, infants, and young children, as well as adults (Spille et al., 2021). In the context of the COVID-19 pandemic, face touching is experiencing particular research interest, because it is associated with the transmission of pathogens to facial mucous membranes. As a result, a substantial number of studies was published that addressed the need to suppress face-touching behaviors (Chen et al., 2020; Lucas et al., 2020; Senthilkumaran et al., 2020). Spontaneously touching the own face means that the person performing the face touch pays little or no attention to the initiation and execution of the sFST, and the accuracy of remembering this behavior is poor (Hall et al., 2007; Harrigan et al., 1987). Furthermore, there is no obvious motivation underlying spontaneous face touches, and they are not intended to serve communicative or social functions as active face touches do (Spille et al., 2021).

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Trigger mechanisms and functional aspects of spontaneous facial self-touches

Previous research findings indicate that sFST occur more frequently when negative emotions, such as anxiety, tension, discomfort, or insecurity, are evoked (Carrillo-Díaz et al., 2020; D'Alessio & Zazzetta, 1986; Goldberg & Rosenthal, 1986; Harrigan, 1985; Knöfler & Imhof, 2007; Moszkowski & Stack, 2007). Recent studies have shown a positive association between trait anxiety and the number of sFST (Carrillo-Díaz et al., 2020; Carrillo-Díaz et al., 2021). In this context, emotion-regulating functions are attributed to sFST (D'Alessio & Zazzetta, 1986; Grunwald et al., 2014; Harrigan, 1985; Moszkowski & Stack, 2007; Mueller et al., 2019; Reissland, Aydin, et al., 2015a; Reissland, Francis, et al., 2015b). Furthermore, sFST may be associated with cognitive load and attentional demands (Grunwald et al., 2014; Harrigan, 1985; Mueller et al., 2019). Studies observed an increase in the frequency of sFST in tasks with increasing complexity and attentional demands (Barroso et al., 1978; Barroso & Feld, 1986). Barroso and colleagues found that higher numbers of sFST were associated with better performances in a memory task and an attentional task (Stroop Color-Word test) (Barroso et al., 1980). Assuming that performance in a task reflects attentional processes, Barroso and colleagues reasoned that sFST may be associated with increased attentional focus. In line with this, Grunwald et al. (2014) and Mueller et al. (2019) found a higher rate of sFST when distracting auditory stimuli were presented during a delayed memory task. However, Grunwald et al. (2014) reported that when distracting sounds or a working memory task were used independently from each other no increase in sFST occurred. Similarly, Densing et al. (2018) did not find an increase in sFST when inducing high stress in the arithmetic part of the Trier Social Stress Test. The various research findings demonstrate that the exact trigger mechanisms of sFST remain unknown. Moreover, most of the interpretations of sFST discussed in the literature are based solely on behavioral data obtained in observational studies. While various interpretations seem plausible, more experimental studies are required to gain substantiated insights (Spille et al., 2021).

Neurophysiology of spontaneous facial self-touches

To date, only one study from our own research lab has investigated the neurophysiological mechanisms of sFST using electrical brain activity (electroencephalography [EEG]). In this, Grunwald et al. (2014) analyzed frequency band-specific cortical power changes before and after sFST. The authors chose an established experimental setting during which EEG changes due to working memory load have been observed before (Grunwald et al., 1999, 2001; Grunwald et al., 2004; Grunwald et al., 2014). Participants exhibited spontaneous facial self-touches during the retention interval of a delayed memory task of complex haptic stimuli when distracting sounds were played (for a schematic representation of the experimental procedure; Fig. 1). The authors observed spectral power changes in the theta band indicating that sFST serve brain regulatory functions and do not merely represent displacement activities (Grunwald et al., 2014). After exploration of haptic stimuli, theta power increased compared with baseline, which has been interpreted as a consequence of the increased memory load due to the storage of the haptic information (Grunwald et al., 2014). Shortly before sFST occurred, theta power decreased. According to the authors, this finding indicates that the distracting sounds during the retention interval were interfering with the maintenance of the memory load. In turn, internal contemplation about the fading memory may have led to emotional reactions. After sFST, theta power returned to

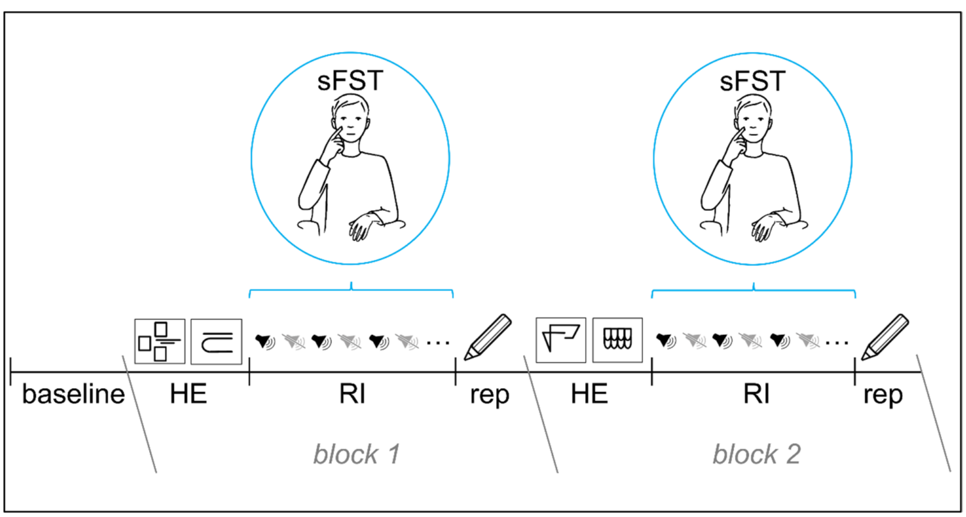

Fig. 1 Schematic representation of the course of the experiment. After 3 minutes of rest (baseline, eyes open), two haptic reliefs had to be explored manually (HE) and subsequently remembered for a retention interval (RI) of 14 minutes. During the RI, a total of 40 distracting sounds alternated with 40 sound-free phases. Spontaneous facial self-touches (sFST) exhibited during the RI were included in the analysis. After the RI, participants were asked to reproduce (rep) the remembered stimuli on a sheet of paper. After the first block (block 1), the procedure was repeated a second time (block 2) with different relief stimuli

the same level as where it had been after haptic exploration. According to Grunwald and colleagues, the increase in the theta band shortly after sFST may represent, on the one hand, successful refocusing of attention and thus maintenance of working memory content. The authors have suggested that the increase in spectral power in the theta band may reflect emotion regulation processes in response to distracting and negative external stimuli. In addition to spectral power changes in the theta band, the authors found significant changes in the beta and gamma bands. Analysis of the beta band showed significant power increases both after haptic exploration and sFST, which the authors have attributed to post-movement beta synchronization (Grunwald et al., 2014). The spectral power of gamma frequency showed, in parallel with the changes of spectral theta power, significant increases after haptic exploration as well as significant decreases before sFST. The increased activity of spectral gamma power has been discussed as a phase coupling process between theta and gamma band oscillations in the context of memory tasks. The spectral power of the alpha frequency did not show any significant changes over the course of the experiment (Grunwald et al., 2014). In addition, the authors analyzed spectral power changes before and after instructed facial self-touches, which had to be performed at request of the investigator in a reference situation without additional working memory demands. No significant changes were detected in any of the frequencies when the spectral power before and after instructed facial self-touches were compared (Grunwald et al., 2014).

Present study

Although sFST is a common behavior and has become an increasing focus of research due to the risk of infection transmission, no other neurophysiological studies on the phenomenon of sFST are available to date. Therefore, and in order to test the theoretical assumptions regarding regulatory functions of sFST, the present study was designed to replicate the results from Grunwald et al. (2014). In a larger sample, we want to examine whether sFST are associated with specific changes in electrical brain activities that indicate the presumed involvement of sFST in the regulation of attentional, emotional, and working memory processes. Because there is a paucity of brain physiological data on sFST to date, a close replication with extension design was used (Brandt et al., 2014). The methods of the study by Grunwald et al. (2014) were reproduced as accurately as possible. However, to extend the generalizability of the results and to remedy methodological deficiencies from the previous study, extensions were made with regard to methodological approaches as well as analytical procedures. Thus, the use of triaxial accelerometers allowed more precise recordings of the temporal structure of sFST and thus an analysis of EEG activity during the skin contact phase of sFST. In addition, the study by Grunwald et al. (2014) did not analyze slow wave activities of the delta frequency. However, since delta band activity has been discussed in relation to cognitive as well as emotional processes (Güntekin & Başar, 2016; Knyazev, 2012), spectral changes in the delta band were considered in the present study. This also is important because neurophysiological sFST research is in its early stages of development, and therefore, an explorative approach is important in order not to miss important findings that would contribute to the further development of the theory on sFST.

Cortical activity before and after sFST during delayed memory tasks (Hypotheses 1a-c, replication of previous study results)

To replicate the findings of Grunwald et al. (2014), frequency band-specific power differences in the delta, theta, alpha, beta, and gamma bands were calculated by comparing the mean spectral absolute powers between consecutive events of the experiment (Fig. 2).

In hypothesis 1a, we expected to find spectral power increases when comparing the resting period (baseline) and a 3-s period after haptic exploration (aHE). In line with the results of Grunwald et al. (2014), we expected significant increases in the spectral power of theta, beta, and gamma during 3-s aHE relative to the baseline due to increasing memory load. Investigations of the delta frequency band have shown increases in spectral delta power after the presentation of memory sets during working memory tasks (Fernandez et al., 2002; Harmony et al., 1996; Harmony et al., 2004). Experimental data also have indicated a similarity in the functional correlates of delta and theta oscillations in relation to cognitive processes (Başar et al., 2001). We therefore expect spectral delta power to also increase aHE.

In hypothesis 1b, we expect to find spectral power decreases when comparing a 3-s period aHE and a 3-s period before sFST. The results of Grunwald et al. (2014) showed a decrease in theta and gamma power shortly before sFST occurred. For comparison of 3-s aHE and a period of 3-s before sFST, we therefore expected to find a decrease in theta and gamma power. For the delta frequency band, similar to the changes in the theta band, we assumed that a distraction of attention during the delayed working memory task is accompanied by a decrease in spectral power before sFST.

In hypothesis 1c, we expected to find spectral power increases in a 3-s period after sFST compared with a 3-s period before sFST. Performance of sFST was thought to be associated with a refocusing of attention on working memory process. Grunwald et al. (2014) observed that the theta and beta band showed similar increased spectral power values after sFST as aHE. In line with these results,

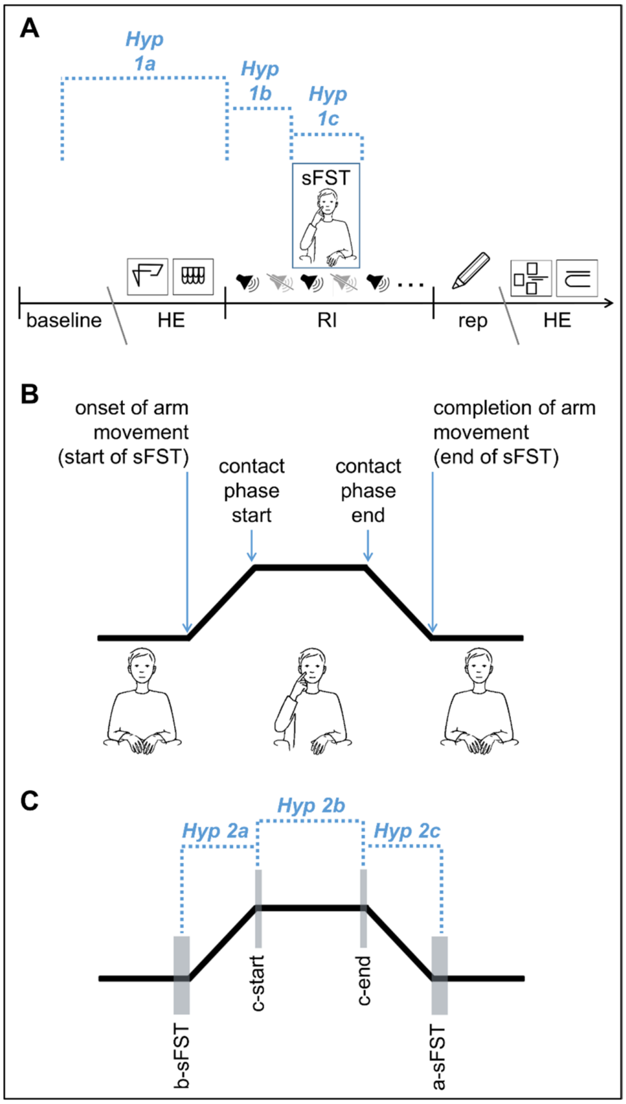

Fig. 2 **a** Schematic representation of the spectral EEG power comparisons (dotted lines) between the 3-minute baseline and 3 s after haptic exploration (HE) (Hyp 1a), between 3 s after HE and 3 s before spontaneous facial self-touches (sFST) (Hyp 1b), and between 3 s before and 3 s after sFST (Hyp 1c) (Adapted from Grunwald et al., 2014, Figure drawn by C. Maiwald). **b** Schematic representation of the course of a sFST with markings of the start of sFST (onset of arm movement), skin contact phase (start and end), and end of sFST (completion of arm movement). **C.** Schematic representation of the spectral EEG power comparisons (dotted lines) between 3 s before spontaneous facial self-touch (b-sFST) and the first 500 ms of skin contact (c-start) (Hyp 2a), between the first 500 ms (c-start) and the last 500 ms (c-end) of skin contact during a sFST (Hyp 2b), and between the last 500 ms of skin contact (c-end) and 3 s after sFST (Hyp 2c)

we expected theta and beta to increase after sFST. Research findings on delta power have suggested that there is a link between increased delta activity and cognitive processes related to attention (Harmony, 2013; Knyazev, 2012) as well as emotional processes (Güntekin & Başar, 2016; Knyazev et al., 2009). Therefore, an increase in spectral power after sFST is expected for the delta band as well.

Neurophysiological changes during the skin contact phase of spontaneous facial self-touches (Hypotheses 2a-c, extension of previous findings)

Grunwald et al. (2014) chose artifact-free segments of 3 s before the sFST started and 3 s after the sFST ended to investigate spectral changes in the context of sFST. Based on these analyses, we know that neurophysiological changes occur between 3 s before sFST and 3 s after sFST. However, for a better understanding of basic mechanisms of sFST, it is necessary to investigate brain physiological processes that take place during sFST. In the present study, in addition to EMG sensors, triaxial accelerometers were implemented, enabling a precise offline analysis of the motion sequence of sFST. By recording the EMG and EEG signals in parallel, it was possible to distinguish the different phases of a facial self-touch (for a schematic representation of an EEG segmentation for sFST see Supplementary Fig. S1).

To extend the original study, we wanted to investigate the specific changes in the EEG that occur during the skin contact phase of sFST. By definition, sFST is the touching of one's own face with one's own hand or fingers, which is why we focus on the skin contact phase in our analysis. To our knowledge, no studies have investigated neurophysiological parameters during skin contact of either spontaneous or active self-touches before. Therefore, we captured the dynamic changes in spectral EEG parameters before, during, and after skin contact of sFST. In hypothesis 2a, we expected to find spectral power changes when comparing a 3-s period before sFST and the first 500 ms of the skin contact phase, in which the facial skin was initially stimulated by touch. In hypothesis 2b, we expected to find spectral power changes when comparing the first and the last 500 ms of the skin contact phase. In hypothesis 2c, we expected to find spectral power changes when comparing the last 500 ms of the skin contact phase and the 3-s period after sFST. For a schematic representation of the hypotheses 2a-c, see Fig. 2.

Materials and Methods

Participants

Sixty healthy volunteers took part in the experiment (30 females; age: mean [M] = 25.72 years, standard deviation [SD] = 3.05; age range 20–35 years). All test subjects were right-handed according to a test of handedness (Oldfield, 1971). None of the participants were taking medications that affect the central nervous system. All participants were naive to any kind of neurophysiological and EEG examinations.

This was necessary to ensure that participants behaved naturally during the retention interval (RI). Test subjects with EEG experience would usually have learned not to move during EEG measurements. Fifty-four of the 60 participants performed at least one sFST at some point in the experiment. A subgroup of 45 participants performed sFST during the RI. The EEG data of one participant had to be excluded due to strong artifacts. Thus, the EEG-data analyses were performed based on whole data sets of 44 participants (25 males/19 females) who performed sFST during the RI. Participants were told that they would participate in an experiment concerning memory effects of haptic exploration. After participants finished the experiment, the goal of the study was unmasked. The study was approved by the Ethics Committee of University of Leipzig Medical Faculty. All participants gave written, informed consent. Participants were paid for participation (10€/h).

Experimental design

The data for the present study were gathered in an experiment investigating sFST during a delayed memory task of complex haptic stimuli (sunken reliefs) (Grunwald et al., 1999, 2001, 2004, 2014). The same experimental setting has been successfully used by Grunwald et al. (2014) to induce sFST. In the present study, the same material and experimental conditions were used as in the aforementioned study. In order to avoid methodological deficiencies from that study, extensions were made with regard to methodological approaches as well as analytical procedures.

The neurobiological analysis of spontaneous, unpredictable, natural behaviors is inherently limited with respect to the trials that can be obtained in laboratory studies. In order to increase the number of interpretable trials in spontaneously occurring behavior, there are few possibilities, including, for example, increasing the duration of the study, tightening the experimental conditions (i.e., a reinforcement of distressing factors and/or memory load) or increasing the number of participants. Because the first two possibilities are difficult to realize for ethical reasons, we chose to increase the number of participants in the present study. Compared with the study of Grunwald et al. (2014), in which 14 participants were tested and 71 sFST trials were included in the analysis, the number of participants in the present study was increased to 60 to obtain a higher total number of sFST trials to be analyzed.

The experiment consisted of two experimental blocks. In each of the two experimental blocks, the participants had to explore two haptic stimuli (HE), remember them for a RI of 14 minutes, and subsequently draw them on a piece of paper (rep). Distracting sounds (e.g., baby crying, explosion, siren) from a free database as well as from the database of International Affective Digitized Sounds (IADS-2) (Bradley & Lang, 2007) were presented during the RI. A detailed description of the sounds is given in the supplemental material. Between the single sounds, there were sound-free phases. Within each RI, 40 sounds and 40 sound-free phases alternated with each other. Across participants, a total of 60 different sounds were played randomly. The durations of the sounds and sound-free phases varied between 7 and 13 s to prevent habituation and anticipation effects. After the first experimental block (HE of 2 stimuli – RI of 14 minutes – rep of 2 stimuli) the procedure was repeated a second time with two different haptic stimuli (Fig. 1).

Participants were seated in a comfortable armchair with the holding equipment (for the haptic relief stimuli) in front of them. Before the experiment began, the procedure was

explained to the participants and one example stimulus as well as three example sounds were presented. Grunwald et al. (2014) used eight example sounds. The sounds were only presented to prepare the participants for the upcoming experiment and to adjust the volume of the loudspeakers. Therefore, the number of example sounds was reduced not to cause any effect by the distracting sounds before the actual experiment began. When the participant had no more questions, the experiment began with a resting phase. Grunwald et al. (2014) applied a baseline of 10 minutes. To avoid unnecessarily lengthening the experimental procedure, the baseline duration was shortened to 3 minutes in the present study. The participants sat quietly and fixated a black dot with their eyes. After rest, the experiment proper started with the haptic exploration task. An opaque screen obscured the participant's hands and the stimulus from vision during exploration. Participants were allowed to explore the reliefs as long as they pleased, with one or both hands. Each sunken relief was milled into a plastic plate of 13 x 13 cm. The order of the sunken reliefs was randomized between subjects. A schematic graph of the sunken reliefs is displayed in Fig. 3. After HE, the opaque screen was removed so the participants could move freely without any obstructions during RI. Participants' eyes remained open during this experimental

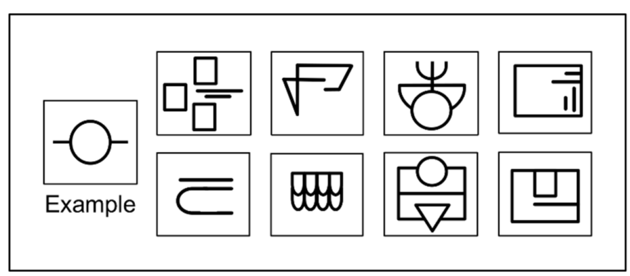

Fig. 3 Sunken relief stimuli and example stimulus. The participant practiced manual exploration on the example stimulus before the experiment began. Each participant was randomly assigned four (two in one block) of the above pictured relief stimuli to be explored during the experiment (Graphic from Mueller et al., 2019, CC BY 4.0)

phase. In the study by Grunwald et al. (2014), the RI lasted 5 minutes, so it would be comparable in length to the other experimental phases—to make sure that the occurrence of sFST during the RI and their possible effect on EEG was not due to chance. As expected, the authors found significantly more sFST during the RI than during the other experimental phases. For this reason, the duration of the RI was extended to 14 minutes in the present study. During the following reproduction period, participants were to draw the structure of the sunken reliefs on a sheet of paper to keep up the illusion of a memory task. After reproduction, the opaque screen was reinstalled and the next two reliefs were presented. In the study by Grunwald et al. (2014), a total of four experimental blocks were run. We reduced the total number of experimental blocks from four to two in order to prevent exhaustion effects.

Technical devices

A 19-channel digital EEG was continuously recorded for all participants in a Faraday Cage during the whole experiment using Ag–AgCl electrodes at standard electrode positions (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, T6, P3, Pz, P4, O1, O2; reference: linked earlobes; International10–20 system (Jasper, 1958)). Movements of the eyes were monitored by horizontal (HEOG) and vertical (VEOG) electrodes. Electrical impedance was kept below 5 kΩ, sampling rate was 256 Hz. Facial self-touch movements and skin contact durations were measured via EMG (two electrodes placed on the dorsal sides of both the left and right forearm above m. extensor carpi ulnaris) and analogous, tri-axial acceleration sensors (ADXL335; attached to the wrists of the participants). The whole experiment was videotaped through a one-way mirror. The recording system (IT-med GmbH, Germany) allowed for parallel, synchronized recordings of EEG, EMG, acceleration sensors, and videos of the whole experimental session.

Data analysis

The present study examined spontaneously occurring self-touches of the face in a study design with controlled trials. To define the type of sFST even more strictly, all self-touches of the hair, head, neck and ears were excluded as well as all sFST with obvious instrumental value (yawning, scratching, nose picking, etc.). Only sFST during RI were analyzed in the present study.

To prepare the data for analyses, EEG recordings were manually marked according to the different phases of the experiment (start – end baseline, start – end HE), artificial events (e.g., body or head movements) and sFST (start – end arm movement and start – end skin contact). The data of the acceleration sensors, EMG and the video recording were used as criteria for the markings. When a sFST was observed in the video, the traces of the accelerometers as well as the EMG were inspected for a visible slope that allowed us to precisely mark the beginning or end of a movement.

Preparation and segmentation of EEG data, ocular correction, artifact rejection, and subsequent calculations of the mean spectral power density were performed with an analytical EEG software package (Brain Vision 1.05, Brain Products, Munich, Germany). Data were filtered using IIR filter (zero phase shift Butterworth filter, low cutoff 0.5 Hz, high cutoff 70 Hz, order 2, notch filter 50 Hz). We used an ocular artifact correction (Gratton et al., 1983) and an automatic artifact rejection with an amplitude criterion of ±80 μV. We performed a spectral analysis of each artifact-free EEG segment using a Fast Fourier Transformation (FFT), after applying a 10% Hanning window. Resolution was set to 0.5 Hz (512 points using zero-padding). Mean spectral absolute power (μV^2) was calculated as the mean amplitude of the spectral lines of the EEG bands (delta: 0.5-4.0 Hz; theta: 4.0–8.0 Hz; alpha: 8.0–13.0 Hz; beta: 13.0–24.0 Hz; gamma: 24.0–49.0 Hz). The following phases were used to calculate the EEG spectral power: Artifact-free EEG segments of the first experimental resting period (3 min, eyes open; EEG with 256 data points per segment) were used to analyze the spectral power at baseline. To analyze the artifact-free spectral power after haptic exploration (aHE), the first 3 EEG segments (3 s with 256 data points each) after the participants ceased exploration, were used. For the detailed analysis of sFST, the following epochs of sFST were segmented: Periods of 3 s before the start (b-sFST) and 3 s after the end (a-sFST) of arm movements as well as 500 ms at the start (c-start) and 500 ms at the end (c-end) of finger-face skin contacts were used to calculate the artifact-free spectral power.

To analyze frequency-specific changes in the continuous EEG, the mean spectral power parameters per channel, participant, and experimental phase were used. For statistical comparisons between spectral power per band and channel, nonparametric Wilcoxon signed-rank tests with adjusted Bonferroni-corrected alpha level (0.05/19, $p_{crit} = 0.002$) were used. Effect sizes for the Wilcoxon signed-rank tests were calculated as $r = z/\sqrt{N}$, where z is the z-score produced by Wilcoxon signed-rank test and N is the sample size. An effect size score of 0.1 indicates a small, 0.3 a medium, and ≥0.5 a large effect (Fritz et al., 2012). For comparisons of group frequencies Binomial tests were conducted. Independent *t*-tests was used for independent group comparisons. All statistical analyses were conducted using SPSS for Windows (version 25.0).

Probability Maps (Inhouse Software) were used to illustrate the topographic distribution of statistical test results. For this purpose, the *p*-values of the error probabilities per frequency range were displayed in graphical form. Empty

(□) or filled squares (■) were used for each individual comparison per channel to mark the significant differences between two periods. An empty square represents a decrease of the spectral power, a filled square corresponds to an increase of the spectral power between two periods The different sizes of the squares represent the strength of the significance. Accordingly, a larger square indicates a higher significance. If a result did not reach the significance value $p \leq 0.05$, it was displayed as a circle. Empty circles (○) indicate the tendency of a decrease and filled circles (●) indicate the tendency of an increase. The data of the current study are available from the corresponding author upon request.

Results

Descriptive statistics

Among the 44 participants who performed sFST during the RI, an average of M = 4.52 (SD = 3.49) sFST per participant were observed. The mean skin contact duration of sFST was M = 2.67 seconds (SD = 3.97). The number of individual sFST during the RI ranged from 1 to 14 sFST. Across the 44 participants, significantly more sFST were performed during the RI (sum = 199) than during all other experimental phases combined (sum = 108; Binomial test $p < 0.001$). Moreover, significantly more sFST occurred during the presentation of distracting sounds (sum = 136) than during the sound-free phases (sum = 63; Binomial test $p < 0.001$). After 36 sFST were rejected due to artifacts, a total of 163 sFST were included in the EEG analyses. Rejected sFST did not differ from included sFST in terms of skin contact duration (t(197) = −647, $p = 0.518$).

Hypotheses 1a-c, replication of previous study results

Hypothesis 1a: Spectral EEG power increases between baseline and after haptic exploration (aHE)

Comparisons of the EEG at rest (baseline) and aHE showed significant increases of the spectral power above all electrodes for the delta, theta (except Cz, P3, P4), beta (except Pz), and gamma bands (Fig. 4). Alpha power increased above frontal electrodes and decreased above parietal regions. Effect sizes of the significant spectral power changes were medium to large (r = 0.4–0.9). Corresponding statistical values of the Wilcoxon tests and effect sizes are presented in Supplementary Table S1.

Hypothesis 1b: Spectral EEG power decreases between after haptic exploration (aHE) and before sFST (b-sFST)

Comparisons of the EEG aHE and b-sFST showed significant decreases of the spectral power for all frequency bands. In addition, a significant increase was recorded in the alpha band (Fig. 5). Globally distributed decreases of spectral power were observed for the delta band (except O1, O2), the beta band (except F4, F7, F8), and the gamma band (F3, F4, F7, F8). The theta power mainly decreased above frontal and temporal regions. In the alpha band, there was a significant decrease in spectral power above frontal areas, whereas there was a significant increase above parietal regions. Effect sizes of the significant spectral power changes were medium to large (r = 0.3–0.8). Corresponding statistical values of the Wilcoxon tests and effect sizes are presented in Supplementary Table S2.

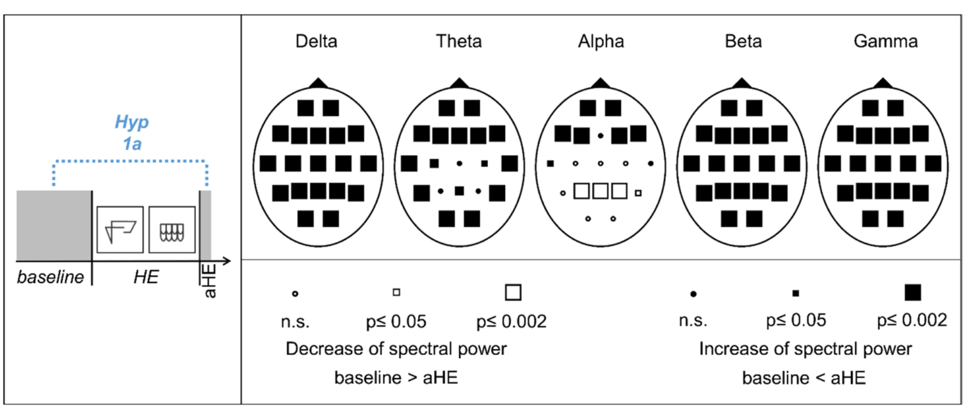

Fig. 4 Schematic representation of hypothesis 1a (Hyp 1a) and Probability Maps for spectral EEG power comparisons between baseline and after haptic exploration (aHE). Results of nonparametric Wilcoxon-tests per channel and frequency band

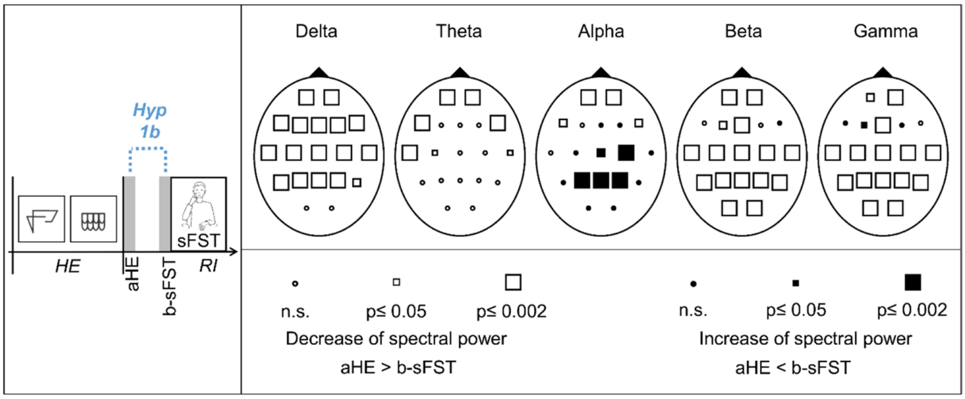

Fig. 5 Schematic representation of hypothesis 1b (Hyp 1b) and Probability Maps for spectral EEG power comparisons between after haptic exploration (aHE) and before spontaneous facial self-touches (b-sFST). Results of nonparametric Wilcoxon-tests per channel and frequency band. RI = Retention Interval

Hypothesis 1c: Spectral EEG power increases between before sFST (b-sFST) and after sFST (a-sFST)

Comparisons of the EEG b-sFST and a-sFST showed significant increases of the spectral power for all frequency bands (Fig. 6). The spectral power of delta frequency showed significant increases above frontocentral and temporal regions. Increases of the theta and alpha band were observed over right prefrontal electrodes. However, the significant changes in theta and alpha did not reach the critical Bonferroni value of $p_{crit} = 0.002$. Bilateral increases over the whole cortex were observed for beta (excluding midline electrodes) and gamma (excluding Fp1, Fp2, F4). Effect sizes of the significant spectral power changes were medium to large (r = 0.3–0.7). Corresponding statistical values of the Wilcoxon tests and effect sizes are presented in Supplementary Table S3.

Hypotheses 2a-c: Neurophysiological changes during the skin contact of spontaneous facial self-touches

Hypothesis 2a: Spectral EEG power changes between before sFST (b-sFST) and start of skin contact (c-start)

Comparisons of the EEG b-sFST and c-start showed significant increases of the spectral power for all frequency bands and additionally significant decreases in the theta and alpha band (Fig. 7). Delta power increased over the whole cortex (excluding O1, O2). Theta, alpha, and beta mainly increased above prefrontal and frontal regions. The spectral power of gamma frequency showed significant increases over the whole cortex (excluding F7, F8, T3, T4, C3, C4). Significant decreases occurred above parietal and occipital regions in the theta band and above centroparietal, temporal, and occipital regions in the

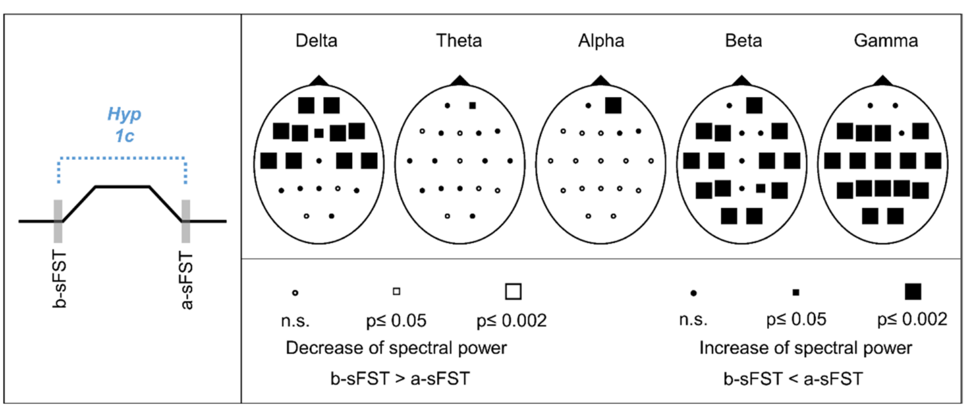

Fig. 6 Schematic representation of hypothesis 1c (Hyp 1c) and Probability Maps for spectral EEG power comparisons between before spontaneous facial self-touches (b-SFST) and after sFST (a-sFST). Results of nonparametric Wilcoxon-tests per channel and frequency band

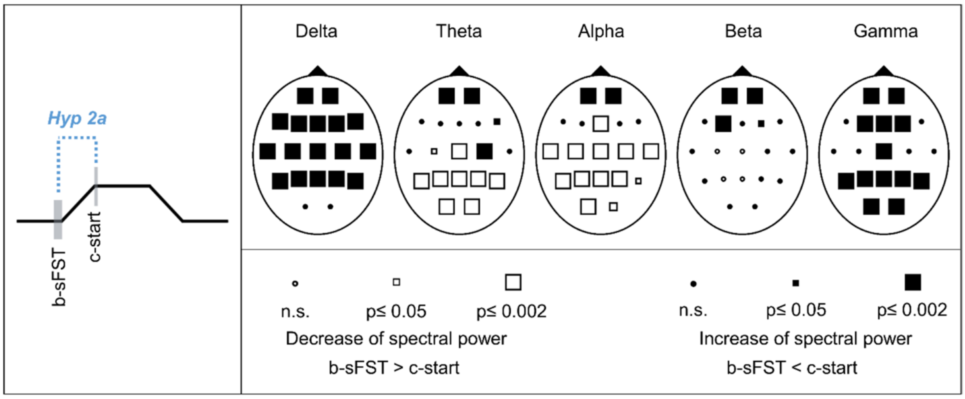

Fig. 7 Schematic representation of hypothesis 2a (Hyp 2a) and Probability Maps for spectral EEG power comparisons between before spontaneous facial self-touches (b-sFST) and start of skin contact (c-start). Results of nonparametric Wilcoxon-tests per channel and frequency band

alpha band. Effect sizes of the significant spectral power changes were medium to large (r = 0.3–0.8). Corresponding statistical values of the Wilcoxon tests and effect sizes are presented in Supplementary Table S4.

Hypothesis 2b: Spectral EEG power changes between start of skin contact (c-start) and end of skin contact (c-end)

Comparisons of the EEG c-start and c-end showed no significant changes of the spectral power for any frequency band (Fig. 8). Significant decreases were observed in delta (Fp2), theta (Fp2, F4), and alpha (Fp2). However, these results did not reach the critical Bonferroni value of $p_{crit} = 0.002$. Corresponding statistical values of the Wilcoxon tests and effect sizes are presented in Supplementary Table S5.

Hypothesis 2c: Spectral EEG power changes between end of skin contact (c-end) and after sFST (a-sFST)

Comparisons of the EEG c-end and a-sFST showed significant decreases of the spectral power for all frequency bands above prefrontal and frontal regions (Fig. 9). Additionally, theta and alpha power increased above centroparietal, temporal and occipital regions. Significant increases of the beta band were observed over frontoparietal electrodes. Effect sizes of the significant spectral power changes were medium to large (r = 0.3–0.7). Corresponding statistical values of the Wilcoxon tests and effect sizes are presented in Supplementary Table S6.

Exemplary for the predominant EEG changes before, during, and after the skin contact phase of sFST, the mean spectral power (box plots) of the electrodes F3, Cz, P4, and O1 is depicted in Supplementary Figs. S2-S6 for all frequency bands.

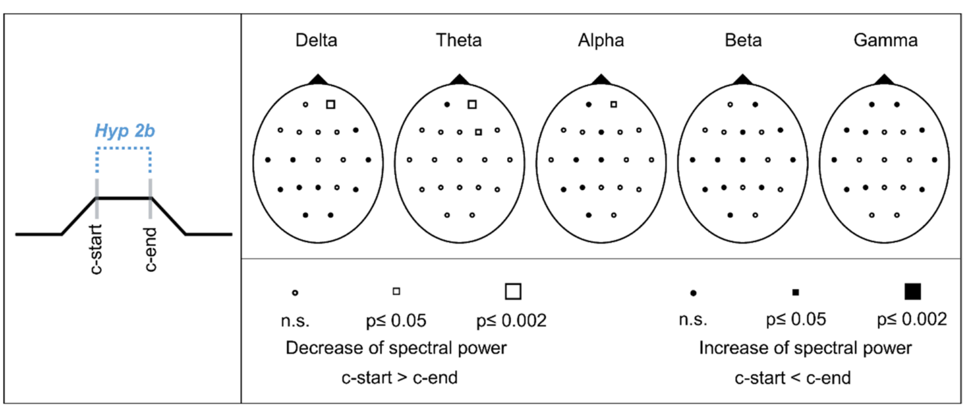

Fig. 8 Schematic representation of hypothesis 2b (Hyp 2b) and Probability Maps for spectral EEG power comparisons between the start of skin contact (c-start) and the end of skin contact (c-end). Results of nonparametric Wilcoxon-tests per channel and frequency band

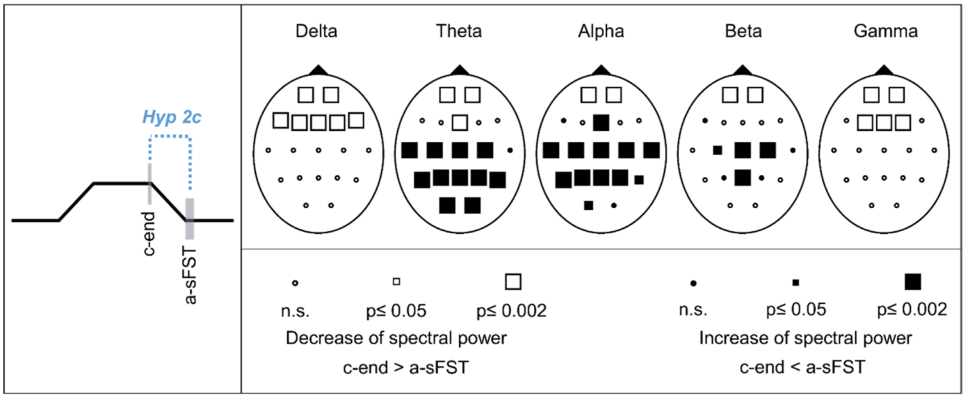

Fig. 9 Schematic representation of hypothesis 2c (Hyp 2c) and Probability Maps for spectral EEG power comparisons between end of skin contact (c-end) and after spontaneous facial self-touches (a-sFST). Results of nonparametric Wilcoxon-tests per channel and frequency band

Discussion

The present study was able to replicate the results of our own previous research on neurophysiological mechanisms of spontaneous facial self-touches (sFST) in a larger sample. In accordance with the results of Grunwald et al. (2014), it was reconfirmed that neurophysiological changes occurred before and after sFST that indicate brain regulatory processes. Moreover, we found that these regulatory effects were activated in the first milliseconds of the execution of sFST. Within the discussion, we will particularly address the results that differ from those found by Grunwald et al. (2014).

Spontaneous facial self-touches may represent working memory and attentional processes

In accordance with hypothesis 1a, significant increases in the delta, theta, beta, and gamma frequency bands were observed after haptic exploration of two sunken reliefs (aHE) compared with a 3-minute baseline. These increases may indicate encoding processes of bottom-up information as well as a high memory load as a consequence of the working memory task (Deiber et al., 2007; Friese et al., 2013; Harmony et al., 2004; Klimesch et al., 1996; Mölle et al., 2002; Onton et al., 2005; Weiss & Rappelsberger, 2000). Studies found focused attention to internal processing and mental effort to be associated with increases in spectral delta (Fernandez et al., 2002; Fernández et al., 1995; Harmony et al., 2004) and theta power (Deiber et al., 2007; Gevins et al., 1997; Jensen & Tesche, 2002). Increases in the gamma band have been discussed in association with the maintenance of object representations held in memory (Mainy et al., 2007; Tallon-Baudry et al., 1999). In line with hypothesis 1b, significant decreases in spectral delta, theta, and gamma power were observed shortly before the self-touch. The decrease in spectral power shortly before sFST may indicate impaired attention to the maintaining processes during the retention interval (RI). Research findings suggest that distracting sounds divert the focus of attention from the memory that should be maintained in a working memory task (Bell et al., 2010; Campbell et al., 2002). According to Grunwald et al. (2014), sFST are performed as a consequence of such interference with maintenance processes. This assumption is supported by the finding that significantly more sFST occurred during the presentation of distracting sounds than in the silences between sounds.

Grunwald et al. (2014) speculated that spectral power increases a-sFST compared to b-sFST may represent processes of working memory maintenance. As expected in hypothesis 1c, significant increases a-sFST were observed that may indicate such brain regulatory functions. For one, delta power increased a-sFST above anterior regions. Such heightened delta power has been associated with processes related to concentration and sustained attention during the retention of information in working memory (Fernandez et al., 2002; Harmony et al., 2004). Furthermore, a-sFST widespread increases of spectral power occurred in the gamma band. Increases in gamma have been associated with the maintenance of sensory working memory representations (Roux & Uhlhaas, 2014). In addition, gamma oscillations are thought to play a special role in integrating multiple feature-specific information into coherent object representations, because stronger activity increases have been found for more complex stimuli (e.g., shapes) than for simple stimuli (e.g., color) (Herrmann et al., 2004; Honkanen et al., 2015). It has been hypothesized that complex stimuli are not processed in a single cortical location but may require distributed neural networks that are spread across several different cortical areas (Christophel et al., 2017; Fuster, 2000). The distributed increase in spectral gamma power a-sFST might reflect the maintenance of a complex object representation in working memory. The haptic stimuli used in the present experimental setting were complex geometric forms and had a variety of features, including material texture, relief (depth, width, start and end points) and orientation. This multitude of features had to be combined into a coherent object presentation for two stimuli. The EEG pattern b-sFST supports the assumption of working memory activation, because gamma power decreased shortly before the occurrence of sFST. Tallon-Baudry and colleagues observed an association between the decreasing performance of the participants and the decreasing energy of spectral gamma power with increasing delay time during a working memory task (Tallon-Baudry et al., 1999). Furthermore, the prefrontal increase in the beta power a-sFST may be related to (re) activation of working memory content (Spitzer & Haegens, 2017). Studies on working memory tasks have found prefrontal increases in the beta band at the end of retention phases when memory content was endogenously "refreshed" in preparation for the imminent comparison task (Spitzer et al., 2010) or when participants were explicitly (retro)-cued to update task-relevant memory contents (Spitzer & Blankenburg, 2011). To test the assumption that the performance of sFST is associated with the maintenance of working memory content, future studies should investigate which behavioral as well as neurophysiological effects are associated with suppression of sFST during working memory maintenance.

The involvement of spontaneous facial self-touches in emotional processes

We observed decreases in spectral theta and alpha power above prefrontal and frontal regions b-sFST. According to Grunwald et al. (2014), neurophysiological decreases in spectral theta power b-sFST may indicate internal contemplation about distracted attention and the fading memory which in turn may have led to emotional reactions. Moreover, the content of the distracting sounds (e.g. baby crying, explosion) may itself have elicited an emotional response. Grissmann et al. (2017) found that interfering stimuli with negative valence during a working memory task led to a decrease in performance and decreased frontal theta activity that could not be explained by additional working memory load. Likewise, the present results showed a decrease in prefrontal theta power b-sFST, which could be due to the distracting sounds.

Furthermore, studies have discussed an association of active emotion regulation, e.g., cognitive reappraisal, with prefrontal power increases in theta (Ertl et al., 2013) and alpha bands (Jackson et al., 2003; Tortella-Feliu et al., 2014). Automatic emotion regulation, in which the emotional meaning of a stimulus is not the explicit focus of the task to be performed, also was mentioned in association with activations in prefrontal areas (Ochsner et al., 2012; Rive et al., 2013). In the present study, the theta and alpha frequency bands showed a decrease in spectral band power above prefrontal regions b-sFST, followed by a power increase above the same areas a-sFST. Although the power increase in the frequency bands a-sFST did not reach the critical Bonferroni criterion, the EEG pattern supports the hypothesis that sFST may be involved in emotional regulation processes, due to the negative valence as well as the distraction effect caused by the sounds. Recent studies have shown a positive association between trait anxiety and the number of sFST (Carrillo-Díaz et al., 2020; Carrillo-Díaz et al., 2021). Because touching one's own face is associated with the transmission of pathogens, a number of researchers addressed the need to reduce face-touching behaviors (Chen et al., 2020; Lucas et al., 2020; Senthilkumaran et al., 2020). However, following the interpretation that sFST serve emotion regulatory functions, it may be inadvisable—particularly for anxious people—to suppress this behavior. Future studies should investigate whether neurophysiological parameters of sFST differ between individuals with high- and low-trait anxiety and assess the consequences of suppressing self-touch behavior in these groups.

Spontaneously touching the own face—a simple behavior with complex causes

It should be emphasized that the underlying trigger mechanisms of sFST are presumably complex in nature. Test subjects did not show increased numbers of sFST when listening to unpleasant sounds from the IADS-2 compared with an unchallenging quiet situation (Grunwald et al., 2014). In another pre-study, participants completed a complex haptic memory task without additional distracting sounds. Again, the test subjects did not show increased numbers of sFST. In the present experiment, information had to be maintained in working memory while distracting sounds were presented. The combination of these two demands resulted in an increased number of sFST. Several studies have found evidence for cognitive-emotional integration processes in the prefrontal cortex (Pessoa, 2008). For example, Perlstein et al. (2002) found activity changes in the prefrontal cortex during working memory tasks in which participants had to remember emotional pictures. These changes were not observed when the emotional pictures were presented without participants being asked to retain information in memory (Perlstein et al., 2002). The prefrontal cortex also has been discussed in association with the emergence of conflict and cognitive control in challenging situations (Botvinick et al., 2001). Conflict monitoring might represent one aspect of a more general monitoring function that detects internal states, signaling a need to intensify or redirect attention or control (Botvinick et al., 2004). The spectral power increases of theta and alpha a-sFST above prefrontal areas could indicate the activation of cognitive processes and not merely reflect emotional regulation processes. However, based on the available data, it is not possible to decide between these possible interpretations and additional work is needed to clarify this issue. To assess whether the observed prefrontal spectral power increases a-sFST are due to either emotional processes or cognitive demands, future studies should use distracting stimuli without emotional valence. Furthermore, it should be tested whether sFST are associated with similar neurophysiological changes when experiments on attention and conflict control (e.g., Stroop task or flanker task) are conducted without additional working memory load.

EEG-pattern of the alpha frequency band during delayed memory task

The present results on the alpha band power differ considerably from those of Grunwald et al. (2014). Contrary to hypotheses 1a-c, there were characteristic changes in spectral alpha power before and after the performance of sFST. The observed parietal decreases aHE compared with baseline may indicate the high memory load as a consequence of memory encoding (Babu Henry Samuel et al., 2018; Sauseng et al., 2005). The increase in frontal alpha power aHE can be interpreted in the context of top-down control mechanisms and inhibition processes that are activated at early stages of information processing (Klimesch et al., 2007; Sauseng et al., 2005; Zhang & Ding, 2010). The centroparietal increases in spectral alpha power b-sFST might reflect a sensory inhibition mechanism in response to the presentation of the distracting sounds to avoid interference with the working memory trace during RI (Babu Henry Samuel et al., 2018; Bonnefond & Jensen, 2012; Tuladhar et al., 2007). In addition, the long duration of the RI in the present study (14 min) may have led to other effects that were not evident in the preliminary study by Grunwald et al. (2014), in which the RI lasted only 5 min. We speculate that the use of longer retention times may be more representative for everyday challenges. Remembering relevant information for several minutes may be difficult due to distracting sensory input as well as mind wandering. In line with that, Baldwin et al. (2017) found an increase in parietal alpha power associated with mind wandering. However, which internal processes led to a decrease in spectral alpha power above frontal regions b-sFST remains unclear. While some studies observed a decrease in frontal alpha power during high memory load (Crespo-Garcia et al., 2013; Stipacek et al., 2003), other authors found opposite results (Michels et al., 2010; Sauseng et al., 2005). The different results may indicate that different regions within the frontal cortex are activated depending on the mental operations required in the different working memory tasks (Crespo-Garcia et al., 2013). The longer duration of the RI in the present study might have led to a higher memory load—accompanied by corresponding changes in the alpha band—than in the preliminary study of Grunwald et al. (2014), in which the RI lasted only 5 minutes. The divergent findings in the alpha band also may be related to the extended number of participants compared with the study by Grunwald and colleagues.

Regulatory processes of brief spontaneous facial self-touches are activated in the first milliseconds of execution

As expected in hypothesis 2a and 2c, the results showed significant changes in all analyzed frequency bands at the beginning and at the of the skin contact phase of sFST, respectively. At the beginning of the skin contact of sFST, increases in the delta, beta, and gamma band were observed above those cortical areas previously discussed in the context of regulatory processes during working memory demands (cf., hypothesis 1c). Moreover, the theta and alpha band showed significant increases above those areas previously discussed in the context of conflict monitoring and emotion regulation processes (cf., hypothesis 1c). Contrary to hypothesis 2b, we did not find significant spectral power changes during the skin contact phase of sFST—instead, the spectral power remained at a constant level during skin contact. At the end of sFST, the spectral power decreased again above those regions where it had increased at the beginning of the skin contact phase. Although the spectral power decreased at the end of sFST, the spectral power after sFST was overall still higher than before sFST. These dynamic spectral power changes over the course of sFST (Supplementary Figs. S2-S6) indicate that the presumed cognitive and emotional regulatory processes were activated at the beginning of the skin contact of sFST and continued for the duration of skin contact.

The skin contact phases of sFST in the present study were of short duration (M = 2.67 s; SD = 3.97). Decades ago, Freedman discussed that brief touch events (3 s or less) differ from continuous sFST (in some instances more than 100 s); not only in their duration, but also in their function (Freedman, 1972). A recent review on sFST also found that the average duration of sFST varied from less than 3 s to more than 10 s (Spille et al., 2021). Assuming that brief sFST are a direct regulatory response to emotionally and cognitively disturbing situations, the question arises whether continuous sFST with longer skin contact phases serve different functions than brief sFST and, accordingly, show different neurophysiological patterns.

In addition to the observed spectral power changes during sFST associated with regulatory processes, we observed significant power changes in the theta and alpha bands above posterior regions. It is unclear which processes led to a decrease in posterior theta and alpha power at the beginning, followed by an increase above the same regions at the end of sFST. As these spectral power changes occurred above areas of motor and sensory cortex, the observed posterior changes may be related to motor (movement of the hand toward the face) or sensory (tactile stimulation by skin contact between finger and face) aspects of sFST. Because we limited the present analysis to the skin contact phase, it cannot be clarified whether motor aspects, sensory skin contact, or an interaction of both led to the observed changes above posterior regions in theta and alpha. In contrast, the increases in spectral beta power above sensorimotor areas a-sFST are consistent with the findings of Grunwald et al. (2014) and may reflect the motor aspects of movement execution of sFST and indicate a post movement beta rebound (Alegre et al., 2004; Kilavik et al., 2013). In addition to the skin contact phase, future studies should investigate spectral power changes that occur during the movement phase of sFST.

Limitations and future directions

In this study, our goal was to examine the spectral power changes that occur during spontaneous self-touches to the face. The experiment is characterized by a variety of independent variables, such as varying working memory load and distracting sounds with emotional content. This also is reflected in the multitude of EEG changes observed in all frequency bands before, during, and after sFST. On the one hand, the challenging experiment rather reflects everyday situations, as opposed to settings in which participants are not allowed to move and are required to perform: for example, stimulus-response tasks that are less complex. On the other hand, the present study setting increases the difficulty of interpreting the neurophysiological parameters, because the trigger mechanisms of sFST are probably complex. Therefore, limitations of the current study as well as recommendations for further work will be given in the following.

Studying spontaneous behaviors within controlled experimental trials is a difficult endeavor since spontaneous behaviors occur with individually varying frequency, are not strictly predictable, and may only be provoked to a limited extent in the context of an experiment. Therefore, neurobiological analysis of spontaneously occurring behavior is inherently limited with respect to the trials that can be obtained in laboratory studies and differs fundamentally from stimulus-response paradigms, in which the number of trials is determined before the experiment. In the present study, the participants performed an average of M = 4.52 (SD = 3.49) sFST. The comparatively small number of trials to be analyzed is an important limitation that also pertains to the investigation of other spontaneous behaviors, such as yawning, epileptic seizures, or lucid dreaming (Guggisberg et al., 2007; Sato et al., 2017; Voss et al., 2009, respectively). Despite these methodological limitations, given the large sample size and the total number of sFST trials, we consider the present data to be suitable for investigating sFST in a biologically representative and reliable manner. To further evaluate the reliability of the EEG measures, future studies could conduct the experimental procedure twice on the same sample to analyze the test-retest reliability of the spectral EEG parameters.

For a better understanding of internal and external trigger mechanisms and functions of sFST, future experimental procedures should make a clearer distinction between possible influencing factors. To address the emotion regulation hypothesis, subjectively experienced emotions should be rated by participants. Moreover, Schweizer et al. (2019) discussed that the positive or negative value to a healthy research participant will usually be relatively low for standardized affective stimuli. Therefore, valence and arousal of emotional stimuli need to be increased in future studies. To investigate the presumed function of sFST regarding attentional processes, different attention tasks should be conducted without applying additional working memory load. In terms of the regulation hypothesis of working memory processes, distractors without emotional valence should be applied. In the present study, we used a haptic working memory task during which EEG changes due to working memory load have been observed before (Grunwald et al., 1999, 2001; Grunwald et al., 2004; Grunwald et al., 2014). Nevertheless, it should be noted that, for example, visual or auditory working memory tasks are more established in EEG research than haptic memory tasks (Li Hegner et al., 2007). Following the hypothesis that sFST occur when maintenance processes are impaired by distractors, working memory tasks in other sensory modalities also should be applied and compared with the results of the present study. Regardless of the sensory modality used in a working memory task to investigate sFST, memory performance should be examined after the execution of sFST compared to a control situation in which sFST are prevented. Furthermore, to test the regulation hypothesis, other biological markers, such as autonomic activity or electrodermal activity, could be examined in addition to neurophysiological parameters.

With respect to the discussion of the risk of infection transmission by touching one's own face, future studies should take a closer look at the specific touched facial areas. In a recent review, Spille et al. (2021) found that most sFST are directed to the middle axis of the face. As the facial mucous membranes (eyes, nose, mouth) can get inoculated with bacteria from the fingertips (Rusin et al., 2002), it should be clarified whether sFST neurophysiologically differ depending on the executing hand (left- or right-handed movements) or touched area of the face. Future studies also should investigate whether body movements without skin contact that occur when using the same experimental setting are accompanied by similar neurophysiological changes as sFST.

Moreover, because sFST seem to occur more frequently than spontaneous touches of other body parts (Spille et al., 2021), it should be clarified whether other types of spontaneous self-touch show different neurophysiological patterns or have similar brain regulatory functions as sFST. A neuroimaging study by Boehme and colleagues recently investigated the processing of self-generated touch and touch by others at cortical levels (Boehme et al., 2019). However, unlike the work of these authors and other research addressing self-touch (Gentsch et al., 2015; Kilteni & Ehrsson, 2020), the present study investigated spontaneously occurring facial self-touches, as opposed to experimental conditions in which participants are instructed to actively touch themselves. Whether phenomena that occur in active self-touch, such as sensory attenuation (Kilteni & Ehrsson, 2020), similarly occur in sFST remains to be answered.

Conclusions

Our results show that brief, spontaneous, facial self-touches are associated with neurophysiological changes indicative of internal regulatory processes. However, it remains unclear what exactly triggers sFST. In the present study, spectral power changes in the delta, theta, alpha, beta, and gamma frequency band were investigated, which occurred before, during, and after the execution of sFST and which were performed during the retention interval of a delayed haptic working memory task. There is evidence to suggest that changes in spectral delta and gamma power during the execution of sFST represent a refocusing of attention on the memory representations to be maintained. Prefrontal changes in theta and alpha power spectra may further indicate involvement in processes of emotional homeostasis. The results show that activations associated with regulatory processes occur in the first milliseconds of sFST, when the hand moves toward the face and touches the facial skin.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13415-022-00983-4.

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Declarations

Conflict of interest All authors claim that there are no conflicts of interest.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of University of Leipzig Medical Faculty.

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Open practices statements All data are available upon request to the corresponding author. The experiment was not preregistered.

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The suppression of spontaneous face touch and resulting consequences on memory performance of high and low self-touching individuals

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Spontaneous touching of one's own face (sFST) is an everyday behavior that occurs primarily in cognitively and emotionally demanding situations, regardless of a persons' age or gender. Recently, sFST have sparked scientific interest since they are associated with self-inoculation and transmission of respiratory diseases. Several studies addressed the need to reduce sFST behaviors without discussing the underlying functions of this spontaneous behavior. In addition, the question of why this behavior occurs very frequently in some individuals (high self-touching individuals, HT) but less frequently in others (low self-touching individuals, LT) has not yet been addressed. For the first time, we distinguished between HT and LT and investigated the behavioral consequences of sFST suppression in these two groups. For this purpose, we examined performance outcomes of 49 participants depending on sFST behaviors during a haptic working memory task. In addition, we assessed personality traits of HT and LT using the Freiburg Personality Inventory (FPI-R). The results of our study reveal that suppressing sFST in HT is negatively related to memory performance outcomes. Moreover, HT show tendencies to differ from LT in certain personality traits. Our results highlight the relevance of distinguishing between HT and LT in future studies of sFST.

The high mortality rate of COVID-19 is currently leading to increased research on various aspects of infection prevention, including suppression of spontaneous facial touch. In this context, spontaneous face-touches are of research interest because they are associated with self-inoculation. When hands touch contaminated surfaces or, via handshake, others people's hands and subsequently touch the own face, pathogens can be transferred to one's own facial mucous membranes[1–3]. Although one study showed that the number of spontaneous touches to the own face (sFST) decreased after handshake[4], the risk of autoinoculation is ubiquitous because sFST also occur in the absence of others[5–7] and viruses can survive on both surfaces[8,9] and fingers[10] for several hours. Spontaneous facial self-touches especially play a central role because no attention is paid to the initiation and execution of sFST by the person performing it, and recall of the behavior is poor[11,12]. Unlike active facial self-touches, sFST have no apparent motivation (e.g. scratching to relieve an itch) and they are not intended to serve communicative functions such as tipping one's forehead[13]. While there is increasing research on the interplay of tactile and motor processes as well as neural processing with regard to active self-touches[14–17], to date there is a lack of research approaches that investigate these processes in sFST.

Spontaneous facial self-touches. Spontaneous face touching is an everyday behavior that occurs in people of all ages, regardless of sex or ethnicity, up to 800 times during 16 waking hours/day[13]. The behavior involves spontaneously touching one's own face with one or both hands. Studies indicated that sFST occur both during social interaction[18,19] and in the absence of others[5–7]. The mean duration of sFST has been reported to be less than 3 s in some studies[6,20,21] and less than 6 s in others[18,22–26]. Most face touches are directed to the midline of the face[13,27]. The sFST behavior occurs more frequently when negative emotions such as anxiety, tension, discomfort, or uncertainty are evoked[28–30]. In this regard, researchers have attributed self-regulatory functions to sFST within emotionally demanding situations[5,6,29,31,32]. Furthermore, researchers have discussed the association

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between sFST and cognitive load and attentional demands. In line with this, our own research group found an increase in sFST when distracting sounds were presented during a delayed memory task[5,6]. Research findings suggested that distracting sounds divert the focus of attention from the memory that should be maintained in a working memory task[33,34]. According to Grunwald et al., sFST are performed as a consequence of such interference[5]. This assumption is supported by the finding that significantly more sFST occurred during the presentation of distracting sounds than in the silences between sounds[6]. Electroencephalographic study results support the hypothesis that sFST serve the regulation of cognitive processes in demanding situations such as working memory tasks[5,35].

Interindividual variability in frequency of sFST. Taking previous studies on sFST into account, the wide range in the frequency of sFST behavior is remarkable. Elder and colleagues observed health care workers while performing their usual duties (e.g. front office, medical examination) and recorded a range of 0–105 sFST across individuals during the two-hour investigation period[36]. In another study, medical students underwent 15 min of observation during the university clinic setting[37]. Among female subjects, the authors observed a range of 0–25 sFST in 15 min, extrapolated to 0–100 sFST/h. According to the authors, the sFST frequency was independent of participants' gender and of wearing glasses[37]. The highest range of interindividual sFST behavior was reported by Kwok and colleagues, who observed medical students during a two-hour lecture. During an average hour the range of observed sFST was 4–153[25]. Despite the observed ranges in the aforementioned investigations, no study has yet distinguished between individuals who rarely exhibit sFST (low self-touching individuals, LT) and individuals who frequently perform sFST (high self-touching individuals, HT). Ralph and colleagues, who studied sFST behavior whilst driving, have first emphasized the high interindividual variability in sFST that could not be explained by age or gender[26]. They have suggested that personality factors may underlie the individual differences and called for intensive research on possible determinants of sFST behavior.

Personality and sFST. A previous study examined the relationship between nonverbal communication behaviors and the two personality traits extraversion and neuroticism[38]. The authors found that self-touching was positively associated with a teacher's rating of another person's neuroticism, while self-reported neuroticism was not related to the touch behavior. Other research findings that examined the impact of sFST on other people indicate that individuals who performed sFST were perceived as more outgoing, dominant, expressive, and interested than people who did not exhibit sFST[22,23]. It is questionable whether these perceived characteristics are actually reflected in manifest personality traits and whether these are associated with the frequency of sFST behavior.

Because insights into the relationship between personality traits and sFST behavior are limited so far, the present study aims to explore whether there are personality traits that are associated with individual sFST behavior. For this purpose, the Freiburg Personality Inventory (FPI-R)[39] was chosen, a German multidimensional personality inventory that measures personality traits on 12 different scales: life satisfaction, social orientation, performance orientation, shyness, irritability, aggression, stress, physical complaints, health concerns, openness, extraversion, and emotionality. Following the call for intensive research on possible determinants of sFST behavior[26], the use of the FPI-R is a suitable approach, insofar as a broad range of personality traits is surveyed.

Previous observational studies have investigated sFST behavior in the context of different situations, without discussing personality traits in relation to sFST. For instance, studies have indicated that the frequency of sFST changed within social interactions. As such, a higher number of sFST was observed when participants unexpectedly had to engage in an informal conversation with an unfamiliar interviewer[18], or when patients talked about emotionally relevant topics with their physicians[40]. Based on these studies, it cannot be concluded whether the experimental situation mainly influenced the sFST behavior or whether the elevated sFST behavior may be explained by stable personality traits such as shyness or emotionality. A higher sFST frequency was also observed during the accomplishment of cognitive tasks requiring the focusing of attention[5,35]. Barroso and colleagues further found that higher numbers of sFST were associated with better performances in a memory task and an attentional task[41]. Again, it is not possible to clarify whether the increase in sFST was due to the cognitive demands of the specific experimental requirements or an interindividual difference in performance orientation.

Because there are currently few findings on the relationship between personality traits and sFST behavior, and study results on external situational factors do not allow a direct inference on personality traits, no predefined hypotheses are stated with regard to the subscales of the FPI-R. We assume that HT differ from LT in their scores on the scales of the FPI-R (hypothesis 1).

Suppression of sFST. Several research groups have recently investigated approaches to suppress spontaneous touching of one's own face in order to reduce self-infection and the spread of respiratory diseases. Pathogens can be transferred to mucous membranes—mouth, nose, eyes—by touching one's own face after having contacted contaminated surfaces with the own fingers[42]. Since most sFST are directed to the midline of the face[13], oral and nasal mucosa are particularly relevant as potential transmission routes. Avoiding sFST should contribute to a reduction of these indirect transmission routes[36].

A number of researchers have discussed that individuals who rate the severity of disease if infected by pathogens as high exhibit reduced sFST behavior. Johnston and colleagues found that perceived severity of infection predicted lower rates of sFST[43]. Similarly, Carrillo-Diaz and colleagues observed that threat perception of COVID-19 was negatively associated with sFST[44]. In contrast, Kwok and colleagues observed a high number of sFST (M = 23 sFST/h) in medical students who had previously attended an infection control course[25]. Another study investigated the prevalence of adherence to preventive measures (e.g. avoiding touching the eyes and nose) in Chinese students during the H1N1 pandemic. 72.3% of those who completed the survey reported not having reduced the frequency of touching their mouths, noses and eyes as compared with the pre-H1N1 period[45]. Accordingly, it is questionable whether education about the risk of infection associated with sFST has a (long-lasting) effect on sFST behavior. The fact that little or no attention is paid to the initiation and performance of sFST[13] impedes efforts to voluntarily suppress sFST. Elder and colleagues who had observed health care workers found that medical staff who stated they frequently avoided sFST actually touched their face at the same rate as those who reported to only occasionally or rarely avoid sFST[36].

Physical barriers that prevent contact between finger and facial skin have recently been explored to reduce the risk of infection during the Covid-19 pandemic. In one study, individuals performed less sFST when wearing latex gloves compared to a control situation without gloves[44]. In another study, tapes were used to prevent the execution of arm flexion that precedes sFST. However, taping the extensor side of the elbow did not result in persistent inhibition of sFST behavior[46]. The influence of protective mouth-nose masks on sFST behavior has currently been the subject of controversy in the research community. Some authors found a negative correlation between wearing a mask and sFST frequency[47,48]. In contrast, some studies reported increased tendencies to touch the face while wearing a face mask[49] and loose mask slipping off the nose that caused more hand contacts with the face[50]. However, other authors did not observe any differences in sFST frequency depending on the wearing of a mask[51].

Another attempt to reduce sFST behavior involves different control measures. Carrillo-Diaz and colleagues used signs reminding participants not to touch the face and observed a lower incidence of sFST when reminder signs had been introduced compared to when control measures had been absent[44]. Several research groups developed smart wearable devices that provide, for example, vibrotactile or auditory feedback that send a warning signal when the hand moves closer to the face, thus preventing sFST[52–55]. D'Aurizio and colleagues found a reduction in sFST behavior when wearing a wearable device, but data on long-term effectiveness are lacking[53]. Furthermore, when wearing a smartwatch, for example, only those sFST executed with the arm wearing the watch are detected. As there seems to be no difference in the frequency of left-handed and right-handed sFST[13], wearing a smartwatch would probably fail to capture a large number of sFST.

Possible consequences of sFST suppression. Although some approaches to suppress or reduce sFST have been shown to be effective in the aforementioned studies, the question of behavioral consequences of suppressing this spontaneous behavior has been neglected until now. It is remarkable how many research groups are currently investigating possibilities to suppress sFST without addressing possible consequences of this suppression, although the underlying psychological mechanisms of sFST are still poorly understood[13]. Following the assumption that sFST serve the regulation of attentional and memory processes[5,6,35,41], it is important to consider whether suppressing this inherent regulatory mechanism also affects behavioral outcomes. Suppressing this spontaneous behavior may have negative consequences on attention focus or memory performance. In particular, the performance of HT may be negatively affected by suppression of sFST, because HT are restrained in their natural frequent sFST behavior and thus are limited in their regulatory repertoire. With respect to the performance of LT, it may not make any difference whether sFST can be executed or not, since LT rarely perform sFST anyway. Based on these considerations, we want to investigate the behavioral consequences of mechanically suppressed sFST during the retention interval of a haptic working memory task in HT and LT.

We hypothesize that in HT, suppression of sFST during a working memory task (immobilized hands) will cause a decrease in memory performance and therefore be associated with poorer performance outcomes than when sFST can be performed freely (free hands) (Hypothesis 2). For LT, we assume that performance outcomes do not differ between the "immobilized hands" and "free hands" conditions (Hypothesis 3).

Materials and methods

Participants. Forty-nine healthy volunteers took part in the experiment (23 female; age: $M = 25.39$ years, $SD = 3.21$; range 20–35 years). All test subjects were right-handed according to a test of handedness[56]. To prevent interfering cognitions about sFST, participants were told that they would participate in an experiment concerning memory effects of haptic exploration. After participants finished the experiment, the goal of the study was unmasked and participants received 10€/h. All participants gave written informed consent. The study was approved by the Ethics Committee of University of Leipzig, Medical Faculty. The procedures used in this study adhered to the tenets of the Declaration of Helsinki.

Experimental design. The experiment consisted of four experimental blocks. In each of the four experimental blocks, the participants had to explore two haptic stimuli (HE of sunken reliefs), remember them for a retention interval (RI) of 14 min and subsequently draw them on a piece of paper (rep). Distracting sounds (e.g. baby crying, explosion, siren) from a free database as well as from the database of International Affective Digitized Sounds (IADS-2)[57] were presented during the RI. A detailed description of the sounds is given as supplementary material. Between the single sounds, there were sound-free phases. Within each RI, 40 sounds and 40 sound-free phases alternated with each other. Across participants, a total of 60 different sounds were played randomly. The durations of the sounds and sound-free phases varied between 6 and 13 s to prevent habituation and anticipation effects. In two of four experimental blocks, mechanical immobilization of the participants' hands and fingers suppressed the execution of sFST. Half of the participants were randomly assigned to the first condition (free hands in blocks 1 and 2; immobilized hands in blocks 3 and 4), whereas the other half of the participants were assigned to the second condition (immobilized hands in blocks 1 and 2; free hands in blocks 3 and 4). A schematic representation of the experimental design and the sunken reliefs is presented in Fig. 1.

Participants were seated in a comfortable armchair with the holding equipment (for the haptic relief stimuli) in front of them. Before the experiment started, the procedure was explained to the participants and one example

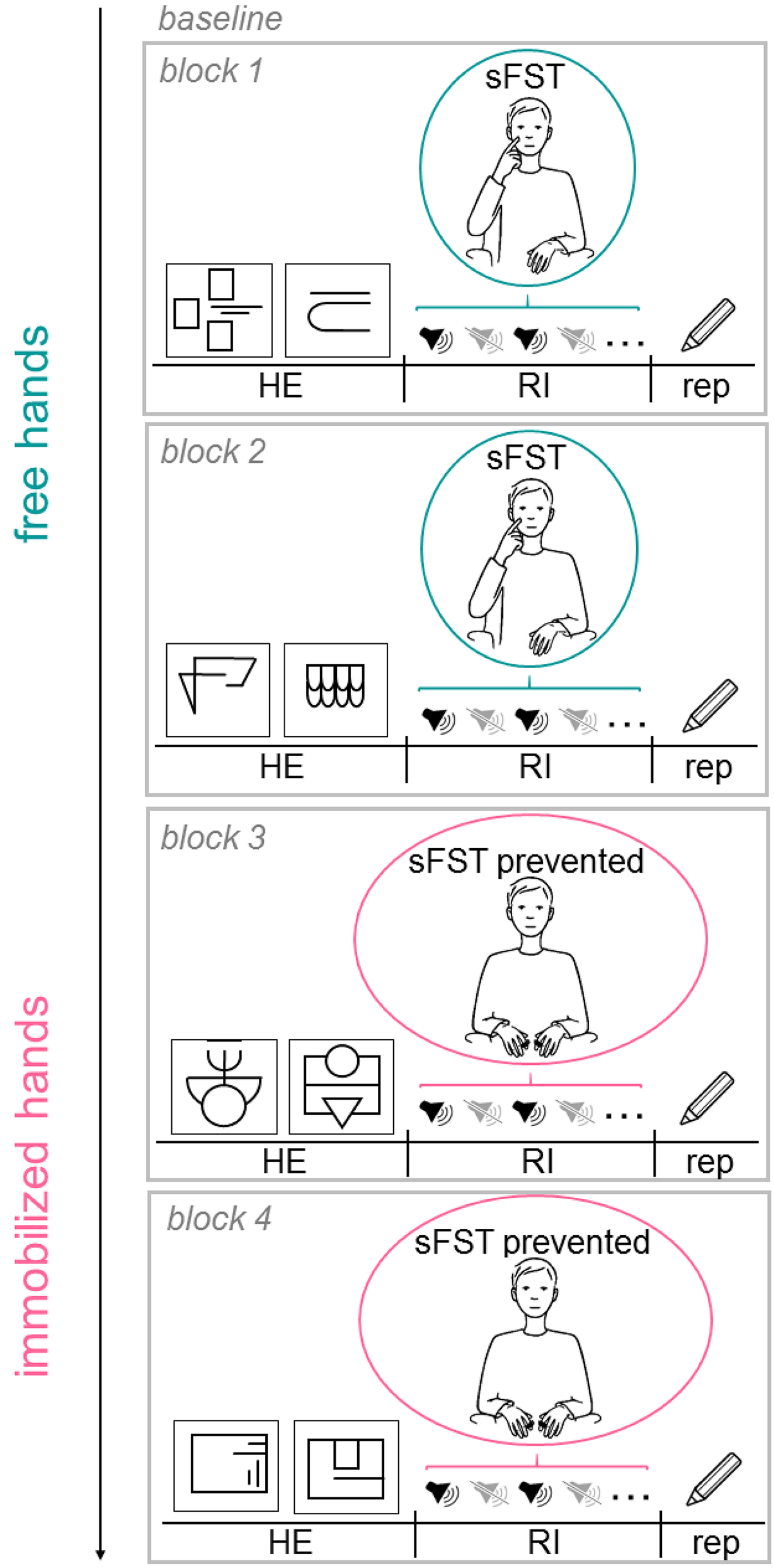

Figure 1. Schematic representation of the course of the experiment. After three minutes of rest (baseline, eyes open), two haptic reliefs had to be explored manually (HE) and subsequently remembered for a retention interval (RI) of 14 min. During the RI, a total of 40 distracting sounds alternated with 40 sound-free phases. After the RI, participants were asked to reproduce (rep) the remembered stimuli on a sheet of paper. After the first block (block 1) the procedure was repeated a second time (block 2). In the "free hands" condition (block 1&2), participants were able to exhibit spontaneous facial self-touches sFST during the RI. In the "immobilized hands" condition (block 3&4), the participants' fingers were loosely fixed during the RI. Thus, the performance of sFST was suppressed. The order of conditions was randomized. Each block consisted of two different relief stimuli. Stimuli were randomized between blocks.

stimulus as well as three example sounds were presented. When the participant had no more questions, the experiment started with the haptic exploration task. An opaque screen obscured the participant's hands and the stimulus from vision during exploration. Participants were allowed to explore the reliefs as long as they pleased; with one or both hands. Each sunken relief was milled into a plastic plate of 13 × 13 cm. The order of the sunken reliefs was randomized between participants. After haptic exploration, the opaque screen was removed and the retention interval began. During the experimental condition "free hands", participants could move freely without any obstructions during RI. Thus, participants were able to exhibit sFST during this condition. During the experimental condition "immobilized hands", participants' index fingers were placed on the holding equipment where they were loosely fixed with hook and loose fastener. Thus, the participants could not move their hands freely and therefore the performance of sFST was suppressed. As a cover story, participants were informed that their finger temperature would be recorded and that they should keep their fingers on the plate steadily. During the following reproduction period, participants were to draw the structure of the sunken reliefs on a sheet of paper. After reproduction, the opaque screen was reinstalled and the next two reliefs were presented.

To explore whether individual differences in personality traits correlate with sFST behavior, we used the Freiburg Personality Inventory[39]. Through the 138 items of the questionnaire 12 personality characteristics were recorded: life satisfaction (FPI-01), social orientation (FPI-02), performance orientation (FPI-03), shyness (FPI-04), irritability (FPI-05), aggression (FPI-06), stress (FPI-07), physical complaints (FPI-08), health concerns (FPI-09), openness (FPI-10), as well as 2 secondary factors extraversion (FPI-E) and emotionality (FPI-N). Higher scores do represent higher expression of the items. The questionnaire was applied at the end of the experiment.

Facial self-touches were measured via EMG (two electrodes placed on the dorsal sides of both the left and right forearm above m. extensor carpi ulnaris) and analogous, tri-axial acceleration sensors (ADXL335; attached to the wrist of the participants). The whole experiment was videotaped through a one-way mirror. The recording system (IT-med GmbH, Germany) allowed for parallel, synchronized recording of EMG, accelerations sensors and videos of the whole experimental session with a recording rate of 256 data points per second. EEG was also recorded but the results will be presented elsewhere.

Data analysis. The present study examined performance outcomes depending on whether participants were able to move their hands freely and perform sFST during RI or whether their hands were immobilized, thus preventing them from executing sFST. To define the type of sFST even more strictly, all self-touches of the hair, head, neck and ears were excluded as well as all sFST with obvious instrumental value (yawning, scratching, nose picking etc.). Even though sFST occurred during all experimental phases, the main analytical emphasis will be on sFST that occurred during RI as we aim to investigate the association between sFST and the maintenance of items in working memory.

The quality of the participants' graphic reproduction of the haptic stimuli was assessed by three independent raters (S.M., M.G. and N.S). The performance outcome was evaluated using a 4-point rating scale with score 1 representing the best outcome (The drawing fully reproduces the overall structure of the target stimulus) and score 4 representing the worst outcome (The drawing does not reproduce the target stimulus). Kendall's Concordance Coefficient (Kendall's W) was used to assess the interrater reliability of the behavioral performance ratings of the participants. Interrater reliability for performance outcome was very good (Kendall's $W = 0.895$, $p < 0.001$).

All statistical analyses were conducted using SPSS for Windows (version 27.0). Alpha was set at 5%. Within subject comparisons were performed via non-parametric Wilcoxon signed-rank tests. Effect sizes for the Wilcoxon signed-rank tests were calculated as $r = z/\sqrt{N}$, where z is the z-score produced by Wilcoxon signed-rank test and N is the sample size. An effect size score of 0.1 indicates a small, 0.3 a medium, and ≥ 0.5 a large effect[58]. Independent samples t-Test were used for independent group comparisons. When the assumptions of an independent samples t-Test were not met, non-parametric Mann–Whitney-U test was applied.

The data of the current study are available from the corresponding author upon request.

Ethics approval. This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of University of Leipzig Medical Faculty.

Results

Descriptive statistics. Over the entire course of the experiment, 36 of the 49 participants exhibited at least one sFST during the "free hands" condition of RI. Within these 36 participants, the number of individual sFST ranged from 1 to 14. Seven participants (19.4% of the 36 participants who showed sFST during the RI) exhibited only one sFST during RI and therefore constituted the group of low self-touching individuals (LT). Eight participants (22.4% of the 36 participants who showed sFST during the RI) exhibited an average of $Mdn = 9.50$ (range 7–14) sFST during RI and therefore constituted the group of high self-touching individuals (HT). The difference in sFST frequency during RI between the two groups was statistically significant ($U = 0.000$, $p < 0.001$). Combining all other experimental phases (baseline, haptic exploration, reproduction), HT showed considerably more sFST than LT, however, this result failed to reach significance (HT: $Mdn = 6$; range 0–9; LT: $Mdn = 1$; range 0–3; $U = 11.000$, $p = 0.054$). The order of experimental conditions ("free hands" vs. "immobilized hands") did not affect the frequency of sFST ($U = 235.000$, $p = 0.302$). Also, performance outcomes did not differ depending on whether individuals were first assigned to the "immobilized hands" or "free hands" condition ($U = 245.000$, $p = 0.411$).

	HT		LT				95% CI	
	M	*SD*	*M*	*SD*	*t(13)*	*p*	Lower	Upper
FPI-01	4.13	1.246	4.86	1.676	0.969	.350	− 0.901	2.365
FPI-02	6.00	1.512	6.86	1.574	1.075	.302	− 0.865	2.580
FPI-03	4.13	1.959	4.29	1.254	0.186	.855	− 1.708	2.029
FPI-04	5.13	1.727	6.00	2.00	0.910	.379	− 1.202	2.952
FPI-05	4.75	1.282	3.86	1.464	− 1.260	.230	− 2.423	0.638
FPI-06	4.25	1.389	3.29	1.380	− 1.345	.201	− 2.513	0.584
FPI-07	4.38	0.916	3.43	1.134	− 1.789	.097	− 2.090	0.197
FPI-08	4.50	1.069	4.86	1.574	0.520	.612	− 1.125	1.840
FPI-09	4.13	1.808	4.14	2.116	0.018	.986	− 2.169	2.205
FPI-10	5.50	2.070	5.43	0.535	− 0.094	.927	− 1.820	1.678
FPI-E	4.38	1.685	4.43	1.618	0.063	.951	− 1.796	1.904
FPI-N	5.38	1.188	4.43	1.188	− 1.138	.276	− 2.744	0.851

Table 1. Hypothesis 1: comparisons of the FPI-R subscales between high and low self-touching individuals. Results of independent samples t-test. FPI-R, Freiburg personality inventory; HT, high self-touching individuals; LT, low self-touching individuals; CI, confidence interval.

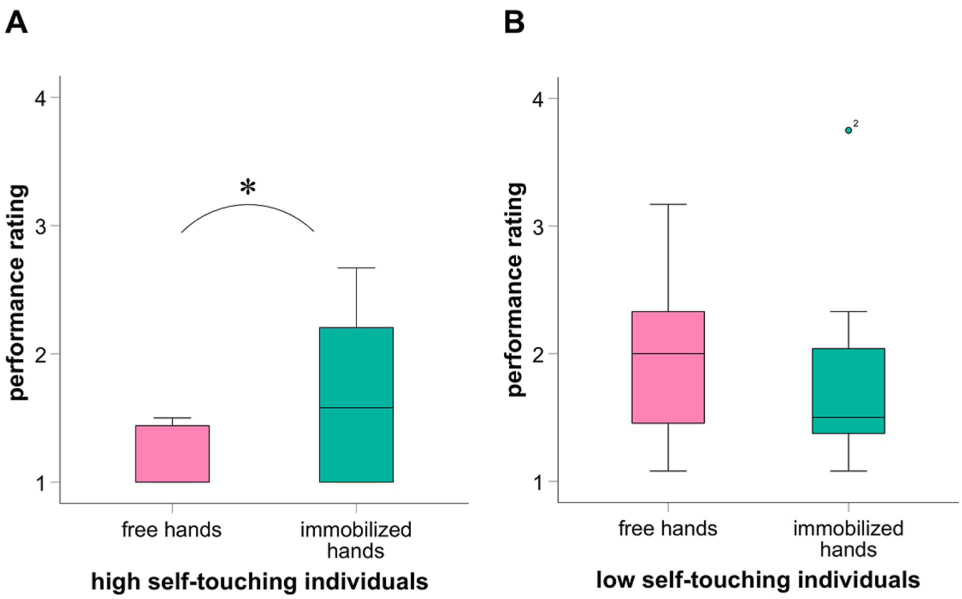

Figure 2. Performance ratings according to different experimental conditions (within-subjects). Score 1 represents the best outcome, score 4 represents the worst outcome. During “free hands” participants could move freely and perform spontaneous facial self-touches (sFST). During “immobilized hands” the performance of sFST was suppressed. Wilcoxon signed-ranked tests revealed that high self-touching individuals showed poorer performance outcomes when sFST were suppressed. $^{*}p < .05$.

Freiburg personality inventory. Contrary to hypothesis 1, HT and LT did not differ in any scale of the FPI-R. However, in the scales irritability (FPI-05), aggression (FPI-06), stress (FPI-07) and emotionality (FPI-N), HT tended to show higher scores than LT, but these differences failed to reach significance (Table 1).

Memory performance. As expected in hypothesis 2, within subjects analysis revealed that HT showed significantly better performance outcomes when they were allowed to exhibit sFST during RI ($Mdn = 1$; range 1.00–1.50) compared to when the execution of sFST was suppressed during RI ($Mdn = 1.58$; range 1.00–2.67; $z = -2.03$, $p = 0.031$, $n = 8$; Fig. 2A). The effect size is $r = 0.72$ and represents a strong effect.

For LT, within-subjects analysis did not reveal any difference in the performance outcomes between the two conditions “free hands” ($Mdn = 2$; range 1.08–3.17) and “immobilized hands” ($Mdn = 1.5$; range 1.08–3.75; $z = -0.51$, $p = 0.344$, $n = 7$; Fig. 2B), as expected in hypothesis 3.

Discussion

The present study was the first to examine personality traits between individuals who frequently perform spontaneous facial self-touches and individuals who rarely perform sFST. Contrary to expectations, we found no significant differences in personality traits between HT and LT. We further investigated the association of mechanical suppression of sFST during the retention interval of a haptic working memory task with performance outcomes in HT and LT. Our results support previous assumptions that sFST are involved in the regulation of attentional and working memory processes and not merely represent displacement activities. A significant negative relationship was found between suppression of sFST and performance outcomes in HT, whereas suppression of sFST in LT was not significantly related to performance outcomes.

Personality traits of high and low self-touching individuals. Contrary to hypothesis 1, HT and LT did not differ significantly in the scales of the FPI-R. However, in the scales stress and emotionality, HT tended to score higher than LT. Individuals who score high on these scales tend to be more sensitive and anxious and are likely to experience high levels of tension, which can result in nervousness and perceived stress. In addition, the analyses revealed that HT—compared to LT—tended to have higher scores in the subscales irritability and aggression. These subscales capture personality traits characterized by excitable, irritable, and unrestrained behavior. Given the small sample size, it would be too early to attribute specific personality traits to HT and LT. Nevertheless, the present findings partially reflect previous results from observational studies. Findings on sFST showed that feelings of tension and uncertainty were correlated with a higher incidence of sFST[18,59]. Moreover, recent research found a positive association between trait anxiety (as measured by the State–Trait Anxiety Inventory, STAI) and sFST frequency[30,44,60] . Items of the scales irritability, stress and emotionality also partially mirror items of the trait anxiety of the STAI. The present findings therefore support the hypothesis that individuals who perform sFST more frequently tend to experience anxiety-related emotions. Future studies on sFST should apply the STAI to confirm the hypothesis that individuals with high trait anxiety generally exhibit higher numbers of sFST than individuals with low trait anxiety. However, as studies have discussed associations between anxiety and other psychological constructs such as stress[61] and aggression[62], future studies should additionally asses each of these different variables for a better understanding of the specific determinants of sFST behavior.

The absence of significant differences between HT and LT in the other scales of the FPI-R indicates that personality traits such as performance orientation, physical complaints, health concerns, openness, and extraversion are not related to the extent of sFST frequency. However, it would be too early to conclude that HT and LT do not differ in these personality traits. Rather, other testing methods that capture personality traits should be conducted on larger samples. In addition, other factors that might impact sFST behavior should be captured. Stefaniak and colleagues have suggested to examine the potential role of social factors such as education[37]. To date, it is not known whether, for example, parental sanctions about lack of table manners or the parents' sFST behavior itself influences children's sFST behavior.

Potential contributors to the high interindividual variability in sFST behavior. The finding that HT and LT did not differ significantly in their personality traits raises a further question: Are situational factors determining for sFST behavior or do individuals—independent of the current situation and environmental stimuli—generally show more or less pronounced sFST behavior that can be explained by factors other than trait anxiety? HT also tended to perform more sFST than LT in the other experimental phases (baseline, haptic exploration, reproduction); indicating that individual sFST behavior occurred irrespective of the experimental phase. To address the question of continuity of sFST behavior in HT and LT, temporal stability as well as cross-situational consistency of sFST behavior need to be examined. Future studies should therefore investigate whether HT execute a greater amount of sFST than LT in other situations—e.g., during non-challenging rest periods, social interaction, or manual tasks.

In addition to varying external situational factors, future research should also ascertain the state of the participants. Following the assumption that sFST are involved in the regulation of emotional and cognitive processes[5,35], a possible explanation for the varying sFST behavior might be the individuals' current mental state. It may be that a person in a balanced state of mind has fewer regulatory needs and therefore exhibits less sFST. Previous research findings on nonverbal behavior have observed a positive relationship between self-touch and depression[63–65]. Findings from clinical patients may be an indication that a person's current mental state—irrespective of environmental circumstances or personality traits—affects sFST behavior.

The suppression of sFST is negatively related to the performance of high self-touching individuals. In accordance with hypothesis 2, we showed that mechanical suppression of sFST in HT was related to poorer performance outcomes in a haptic memory task compared to when HT were able to exhibit sFST. Previous findings provided evidence that higher numbers of sFST are related to better performance in attention and working memory tasks[41]. The observation that sFST suppression in HT was related to poorer performance outcomes supports the hypothesis that sFST serve to regulate attentional and working memory processes[5,6,35,41]. Future studies should conduct attention tasks without additional working memory load, in order to make a clearer distinction between the regulation of attentional and working memory processes by sFST.

Moreover, it remains to be identified whether functions of emotion regulation, which have been discussed in the context of sFST[5,35], are likewise negatively affected by the suppression of sFST. This question is particularly relevant to everyday life of anxious people who exhibit elevated sFST behaviors. Studies that have found a significant link between the frequency of sFST and trait anxiety[30,44,60] did not address the possible behavioral as well as neurobiological functions of sFST in anxious individuals. On the one hand, Carrillo-Diaz and colleagues described sFST as "motor expression of anxiety"; on the other hand, they attributed emotion-regulating functions to sFST[44]. Observational studies that found increased sFST behavior in infants in response to emotionally stressful situations similarly discussed sFST as infancy self-comforting behavior[31,66,67]. It remains unanswered whether frequent sFST behavior actually reduces anxiety, or whether sFST behavior is no more than a physical manifestation of trait anxiety. For this purpose, studies should determine whether the ability of self-regulation in an emotionally demanding situation is impaired when the execution of sFST is suppressed.

To support the assumption of emotion-regulating functions of sFST, future investigations could—in addition to behavioral data or EEG analyses—record biological parameters such as heart rate or skin conductance. Previous literature relates increases in autonomic activity to increased emotional arousal[68–70]. A recent study examined the relationship of active self-soothing touch and cortisol responses to stress[71]. The authors found that, compared to a control group, participants providing self-soothing touch had reduced cortisol secretion responses to socio-evaluative stress. So far, it has not been investigated whether similar mechanisms are involved in spontaneous self-touch.

Do low self-touching individuals possess alternative regulatory mechanisms? As expected in hypothesis 3, the performance outcomes of LT, i.e., individuals who performed only one sFST during the RI, were not impaired after the mechanical suppression of sFST. This raises the question of whether LT possess alternative regulatory mechanisms that were not affected by the suppression of sFST by means of immobilized hands. So far, it is unclear whether the motor aspect of sFST (movement of the arm and hands toward the face), the sensory aspect (contact between finger and facial skin), or an interaction of motor and sensory aspects is central to the hypothesized regulatory functions of sFST[6,35]. Low self-touching individuals may perform compensatory motor actions, such as straightening the upper body, moving the feet, or changing the sitting position, which were not recorded in the present study. Future studies should therefore capture body movements that do not result in a touch event to determine whether they occur more frequently during sFST suppression.

Spontaneous self-touches of other body parts. In the present study, we focused on spontaneous touches of the own face, since they occur more often than spontaneous touches of other body parts[29,59]. So far, no studies have addressed why the face is such a predominant goal. The proximity of the cortical representation of the hand and face might be related to the overall high frequency of sFST compared to self-touches of other body parts[13]. Furthermore, the potential role of the facial nerve as well as the trigeminal nerve, which is part of the facial feedback of emotional expression[72], is yet unclear[6]. Nevertheless, it would be insightful to ascertain whether HT and LT also differ in terms of spontaneous self-touches to other body parts. For example, fidgeting (hand-to-hand behavior) has been theoretically related to self-regulation[73,74]. The same holds true for other self-directed behaviors that have also been observed in primates[75–77]. In this context, another unresolved question is whether continuous touches such as stroking, which can last up to 100 seconds[74], have a different function than short touches such as sFST, which have been reported to last shorter than 3 seconds[13]. Future studies should therefore further investigate the relationship between sFST and other self-touch behaviors, quantifying their influence on performance outcomes and emotion regulation.

Limitations and future directions. Our study was the first to address differences between individuals exhibiting frequent (HT) or low (LT) sFST behavior. Because no study has made this distinction so far, we have not been able to refer to an existing cutoff value that defines individuals as HT or LT. Studying spontaneous behaviors within controlled experimental trials is a difficult endeavor since spontaneous behaviors are not strictly predictable and may only be provoked to a limited extent in the context of an experiment. It is therefore difficult to predict the number of sFST per participant. The present study results may provide a cutoff value for following studies to classify individuals as either HT or LT.

The present study investigated behavioral consequences of sFST suppression in HT and LT. For this purpose, sFST were suppressed during retention intervals by loosely fixating the participants' index fingers with hook and loose fastener. This experimental condition represents a persistent sensory stimulation of the index fingers. We cannot exclude the possibility that the persistent sensory stimulation of the fingers may have an impact on the participants' attention focus or regulatory mechanisms. Therefore, to prevent the potential impact of sensory stimulation, future studies should use other methods to suppress sFST. For example, a shield could be installed above the participants' shoulders, preventing the face from being touched by the own hands.

The finding that suppression of sFST has differential behavioral consequences on HT and LT should provide an incentive to distinguish between these two groups in future studies on sFST. Regarding respiratory infection transmission through sFST, the appropriateness of suppressing sFST using methods such as smart wearable devices should be critically examined. Moreover, researchers discussed the volitional suppression of sFST using behavioral strategies such as awareness training[78]. However, the active and intentional suppression of sFST might require additional cognitive resources[13]. Thus, it should be addressed whether HT experience even greater cognitive performance impairments due to additional mental effort during the volitional suppression of sFST. Alternatives that do not entirely suppress sFST behavior, such as better hand hygiene, should be focused to ensure that individuals who exhibit frequent sFST behavior do not experience negative consequences associated with the suppression of sFST.

Conclusion

Consistent with our expectations, we found that suppression of sFST has different behavioral consequences depending on whether individuals exhibit frequent or infrequent sFST behavior. Individuals who frequently perform sFST show poorer performance outcomes when sFST were suppressed during the retention interval of a working memory task. High and low self-touching individuals do not seem to differ in personality variables measured by the FPI-R, which raises several questions: Why do certain individuals exhibit frequent sFST behavior, while others rarely perform sFST? Is sFST behavior a stable behavioral trait or are situational factors determining the frequency of sFST? Future studies should consider possible causes, personality variables, contextual factors as well as functions of sFST in a more differentiated way.

Data availability

All data are available upon request to the corresponding author. The experiment was not preregistered.

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Author contributions

J.S.: data curation, formal analysis, visualization, writing-original draft. M.G.: conceptualization, funding acquisition, methodology, project administration, resources, supervision, writing-review & editing. S.M.: software, writing-review & editing. S.M.: investigation, writing-review & editing.

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Competing interests

The authors declare no competing interests.

Additional information

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3. Zusammenfassung

Dissertation zur Erlangung des akademischen Grades Dr. rer. nat

Titel:	EEG Korrelate und Gedächtnisleistungen bei spontanen fazialen Selbstberührungen
Eingereicht von:	Jente Lina Spille
Angefertigt an:	Medizinische Fakultät der Universität Leipzig, Paul-Flechsig-Institut – Zentrum für Neuropathologie und Hirnforschung, Haptik-Forschungslabor
Betreut von:	PD Dr. Martin Grunwald
Eingereicht im:	Juli 2022

Obwohl spontane Berührungen des eigenen Gesichts (sFST) zu den häufigsten Körpereigenberührungen zählen und täglich zwischen 400 und 800 Mal ausgeführt werden (Spille et al., 2021), sind grundlegende Fragen zu Auslösemechanismen, Funktionsweisen und psychophysiologischen Prozessen dieses Verhaltens bislang nicht beantwortet. Im Rahmen der COVID-19-Pandemie rückten sFST in den Fokus des allgemeinen als auch wissenschaftlichen Interesses, da sie als Risiko für die Übertragung von Pathogenen gelten und somit einen relevanten Aspekt im Rahmen von Maßnahmen zur Eindämmung der Pandemie darstellten (World Health Organization, 2020). Die Forderung, das Berühren des eigenen Gesichts zu unterbinden, wurde einerseits in der Öffentlichkeit laut, andererseits befassten sich diverse Forschergruppen mit der Frage, wie sFST effektiv unterdrückt werden können. So wurde der Einfluss physischer Barrieren wie Mund-Nasen-Schutzmasken (Guellich et al., 2021; Lucas et al., 2020; Tao et al., 2020) oder Handschuhe (Carrillo-Díaz et al., 2021b) sowie der Einsatz tragbarer Geräte mit vibrotaktilen oder akustischen Warnsignalen (Bai et al., 2021; D'Aurizio et al., 2020; Michelin et al., 2021) auf das sFST-

Verhalten untersucht. Obwohl Forschungsbefunde darauf hinweisen, dass sFST einen inhärenten Regulationsmechanismus in emotional und kognitiv belastenden Situationen darstellen (Barroso et al., 1980; Moszkowski & Stack, 2007; Mueller et al., 2019), wurde in den genannten Studien nicht thematisiert, welche Auswirkungen eine Verhinderung dieses spontanen Verhaltens mit sich bringen könnte. Um die Funktionen von sFST adäquat beschreiben und somit mögliche Konsequenzen bei deren Verhinderung einschätzen zu können, müssen psychophysiologische Prozesse, die sFST zugrunde liegen, untersucht werden.

In der ersten dieser Dissertation zugrundeliegenden Studie (Spille et al., 2022a) wurden Befunde einer früheren EEG-Studie von Grunwald *et al.* (2014) anhand einer größeren Stichprobe (N = 60) repliziert. Im Rahmen einer verzögerten haptischen Arbeitsgedächtnisaufgabe mussten die Versuchspersonen zwei Reliefstimuli haptisch explorieren, diese über eine Behaltensphase von 14 Minuten im Gedächtnis aufrechterhalten und anschließend zeichnerisch reproduzieren. Innerhalb der Behaltensphasen wurden abwechselnd 40 auditive Distraktoren und 40 geräuschfreie Phasen dargeboten. Dieser Ablauf erfolgte zwei Mal mit jeweils unterschiedlichen Stimuli. Analysiert wurden insgesamt 163 einzelne sFST-Ereignisse, die während der Behaltensphasen auftraten. Spektrale Leistungsänderungen in den Frequenzbändern Delta (0,5 – 4,0 Hz), Theta (4,0 – 8,0 Hz), Alpha (8,0 – 13,0 Hz), Beta (13,0 – 24,0 Hz) und Gamma (24,0 – 49,0 Hz) wurden über den Verlauf des Experiments sowie vor, während und nach der Ausführung von sFST analysiert.

Die Erstbefunde aus Grunwald *et al.* (2014) konnten für die Frequenzbänder Theta, Beta und Gamma weitestgehend repliziert werden. Kurz nach der haptischen Exploration der zu merkenden Reliefstimuli zeigte sich eine erhöhte spektrale Leistung im Theta- und Gamma-Frequenzband, welche mit der Speicherung und Aufrechterhaltung von komplexen Objektpräsentationen im Arbeitsgedächtnis zusammenhängt (Deiber et al., 2007; Gevins et al., 1997; Honkanen et al., 2015; Jensen & Tesche, 2002; Roux & Uhlhaas, 2014; Tallon-Baudry et al., 1999). Die erhöhte spektrale Leistung im Theta- und Gamma-Frequenzband sank kurz vor Beginn der sFST signifikant ab, was darauf hinweist, dass die Aufrechterhaltung der Informationen im Arbeitsgedächtnis beeinträchtigt wurde. Forschungsergebnisse deuten darauf hin, dass auditive Distraktoren die Aufmerksamkeit von den aufrechtzuerhaltenden Informationen im Gedächtnis ablenken (Bell et al., 2010; Campbell et al., 2002). Laut Grunwald *et al.* (2014) werden sFST als Folge einer solchen Interferenz ausgeführt. Diese Annahme wird durch den Befund gestützt, dass signifikant mehr sFST während der

Präsentation von auditiven Distraktoren auftraten als in den Pausen zwischen den Distraktoren. Zudem konnte beobachtet werden, dass die spektrale Theta- und Gamma-Leistung kurz nach Beendigung der sFST erneut signifikant anstieg. Diese dynamischen spektralen Leistungsänderungen weisen darauf hin, dass durch das spontane Berühren des eigenen Gesichts regulative Prozesse aktiviert wurden, die mit einer Wiederherstellung der mentalen Gedächtnisrepräsentationen zusammenhängen. Möglicherweise sind sFST zudem an emotionalen Regulationsprozessen beteiligt, die durch die negative Valenz (z.B. Babygeschrei, Explosion, Sirene) oder den Ablenkungseffekt der dargebotenen auditiven Distraktoren ausgelöst wurden. Diese Annahme wird durch die Beobachtung unterstützt, dass die spektrale Leistung des Alpha- und Theta-Frequenzbands im Verlauf der sFST über präfrontalen und frontalen Gebieten zunahm. Studien diskutieren spektrale Leistungszunahmen im Theta- (Ertl et al., 2013) sowie Alpha- (Jackson et al., 2003; Tortella-Feliu et al., 2014) Frequenzband im Zusammenhang mit aktiver Emotionsregulation. Spontane Emotionsregulation, bei der die emotionale Bedeutung eines Reizes nicht explizit im Fokus der Aufgabenstellung liegt, wurde ebenfalls in Verbindung mit Aktivierungen in präfrontalen Bereichen beschrieben (Ochsner et al., 2012; Rive et al., 2013). Weiterhin wurden signifikante Zunahmen der spektralen Beta-Leistung im Zusammenhang mit sFST beobachtet, welche motorische Aspekte der Bewegungsausführung von sFST wiederspiegeln und auf einen Beta-Rebound nach Beendigung der sFST hinweisen (Alegre et al., 2004; Kilavik et al., 2013).

Erstmals wurden in Studie 1 (Spille et al., 2022a) darüber hinaus die spektralen Veränderungen des Delta-Frequenzbands im Zusammenhang mit sFST untersucht. Die spektrale Delta-Leistung nahm kurz nach Beendigung der sFST signifikant zu, was im Zusammenhang mit einer Fokussierung der Aufmerksamkeit auf internale Prozesse diskutiert wird (Fernández et al., 1995; Harmony et al., 2004). Weil ein erhöhter Aufmerksamkeitsfokus auf internale Repräsentationen eine Kernfunktion des Arbeitsgedächtnisses darstellt (Harmony, 2013), unterstützen die Befunde zum Delta-Frequenzband die Hypothese, dass sFST der Regulation von Arbeitsgedächtnisprozessen dienen.

Eine zusätzliche Weiterentwicklung gegenüber der Studie von Grunwald *et al.* (2014) bestand in der Analyse der frequenzbandspezifischen Leistungsänderungen *während* der Ausführung von sFST. Dazu wurden die ersten sowie die letzten 500 Millisekunden der Hautkontaktphase jeder sFST segmentiert und analysiert. Der Beginn der Hautkontaktphase ist definiert durch den initialen Kontakt zwischen Finger- und Gesichtshaut, wohingegen das Ende der Hautkontaktphase durch den Moment charakterisiert ist, in dem sich der Finger von der Gesichtshaut löst. Zu Beginn der Hautkontaktphase wurden signifikante

Leistungszunahmen im Delta- und Gamma-Frequenzband beobachtet, die zuvor im Zusammenhang mit kognitiven Regulationsprozessen beschrieben wurden. Diese spektralen Parameter blieben während der Hautkontaktphase auf einem stark erhöhten Niveau, wohingegen sie nach Beendigung der sFST wieder absanken. Trotz dieses spektralen Leistungsabfalls nach Beendigung der sFST war die spektrale Leistung nach der sFST insgesamt höher als kurz vor Beginn der sFST. Diese dynamischen spektralen Leistungsänderungen über den Verlauf einer sFST deuten darauf hin, dass die vermuteten Regulationsprozesse zu Beginn des Hautkontakts aktiviert und über die gesamte Dauer der Hautkontaktphase aufrechterhalten wurden.

In Studie 2 (Spille et al., 2022b) der vorliegenden Dissertation wurde der Frage nachgegangen, welche Konsequenzen eine Verhinderung von sFST auf die Gedächtnisleistung von Individuen hat. Dazu wurde das Studiendesign von Studie 1 (Spille et al., 2022a) angewandt und um zwei Experimentalblöcke erweitert, in denen die Versuchspersonen während der Behaltensphasen keine sFST ausführen konnten („immobilisierte Hände“), indem die Finger der Versuchspersonen in einer Haltevorrichtung locker in einer Klettverschlussschlaufe fixiert wurden. In den beiden anderen Experimentalblöcken konnten die Versuchspersonen sich frei bewegen („freie Hände“), wodurch die Ausführung von sFST nicht beeinflusst war. Als Maß für die Gedächtnisleistung diente die durch drei unabhängige Rater bewertete Reproduktionsleistung der Reliefstimuli. In Studie 2 (Spille et al., 2022b; N = 49) wurde erstmals in der sFST-Forschung zwischen Individuen unterschieden, die häufig (high self-touching individuals, HT) und selten (low self-touching individuals, LT) sFST ausführen. Die Analyse der Gedächtnisleistungen in der Gruppe der HT zeigte, dass diese signifikant schlechtere Leistungen erbrachten, wenn in der vorangehenden Behaltensphase die Ausführung von sFST verhindert wurde, verglichen mit der Leistung, wenn in der vorangehenden Behaltensphase die Ausführung von sFST unbeeinträchtigt war. In der Gruppe der LT wurde ein solcher Effekt nicht beobachtet. Die Gedächtnisleistung der LT unterschied sich nicht in Abhängigkeit davon, ob in der vorangehenden Behaltensphase die Ausführung von sFST verhindert wurde oder nicht.

Ein weiteres Teilziel von Studie 2 (Spille et al., 2022b) verfolgte die Frage, ob sich HT und LT in ihren Persönlichkeitsmerkmalen unterscheiden. Gemessen an den Skalen des Freiburger Persönlichkeitsinventars (FPI-R; Fahrenberg et al., 2001) konnten keine signifikanten Unterschiede zwischen den beiden Gruppen beobachtet werden. Es zeigten sich jedoch Tendenzen dahingehend, dass HT höhere Werte in den Skalen Stress, Emotionalität, Reizbarkeit und Aggression aufwiesen. Personen, die auf diesen Skalen hohe Werte erreichen, sind tendenziell empfindlicher, ängstlicher, angespannter und zeichnen sich durch erregbares, reizbares und unbeherrschtes Verhalten aus.

Die Befunde der vorliegenden Dissertation liefern einen Beitrag zur Weiterentwicklung der Theorie zu sFST. Einerseits konnten Ergebnisse der bis dato einzigen EEG-Studie zu sFST (Grunwald et al., 2014) repliziert werden. Die Untersuchungen aus Studie 1 (Spille et al., 2022a) konnten zeigen, dass die Ausführung von sFST mit charakteristischen neurophysiologischen Parametern zusammenhängt, die auf interne kognitive sowie emotionale Regulationsprozesse hinweisen. Die Befunde aus Studie 2 (Spille et al., 2022b) demonstrieren, dass es negative Konsequenzen auf die Gedächtnisleistung haben kann, wenn Personen in ihrem natürlichen sFST-Verhalten eingeschränkt werden. Dies offenbart die Problematik des Bestrebens, ein vorwiegend unbewusstes Verhalten zu unterdrücken, dessen funktionale Bedeutung für den menschlichen Organismus bislang nicht hinlänglich erforscht ist.

Neben den gewonnenen Erkenntnissen sind insbesondere auch die neuen Fragestellungen zu betonen, die sich aus der vorliegenden Arbeit ergeben. Die Hautkontaktphasen der untersuchten sFST waren von kurzer Dauer ($M = 2{,}67$ Sekunden; $SD = 3{,}97$). Freedman (1972) diskutierte bereits vor Jahrzehnten, dass kurze sFST sich möglicherweise in ihrer Funktion von länger andauernden (bis zu mehreren Minuten; Zhang et al., 2020) unterscheiden. Es stellt sich die Frage, ob sFST mit länger andauerndem Hautkontakt ähnliche neurophysiologische Muster aufweisen, oder ob kurze sFST in ihrer Funktion eine Besonderheit unter den fazialen Selbstberührungen darstellen. Zudem konnte nicht hinlänglich beantwortet werden, wieso manche Individuen häufig sFST ausführen, während andere ein weniger ausgeprägtes sFST-Verhalten zeigen. Ist das sFST-Verhalten ein stabiles Verhaltensmerkmal oder bestimmen situative Faktoren die Häufigkeit von sFST? Wenn die Verhinderung von sFST negativ mit der Gedächtnisleistung von HT zusammenhängt, ist auch die Fähigkeit zur Emotionsregulation durch die Unterdrückung von sFST beeinträchtigt? Diesen und weiteren Fragen sollte in künftigen experimentellen Studien nachgegangen werden.

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5. Anlagen

5.1. Darstellung des eigenen Beitrags

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Darstellung des eigenen Beitrags

Publikation: Cognitive and emotional regulation processes of spontaneous facial self-touch are activated in the first milliseconds of touch: Replication of previous EEG findings and further insights. (Cognitive, Affective, & Behavioral Neuroscience)

Autor:innen: Jente L. Spille, Stephanie M. Müller, Sven Martin & Martin Grunwald

Hiermit bestätigen wir, dass Frau Jente Lina Spille als Erstautorin der oben genannten Publikation alleinig für die Erstellung des Manuskripts verantwortlich war, inklusive der dafür notwendigen Arbeitsschritte wie Literaturrecherche, Datenauswertung, Darstellung der Ergebnisse sowie Interpretation dieser vor dem Hintergrund des aktuellen Forschungsstandes. Frau Spille übernahm die Einreichung des Publikationsmanuskripts selbständig unter Einarbeitung der Kommentare der Ko-Autor:innen.

Datum: 23.06.22 Unterschrift: ....
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Datum: 23.6.22 Unterschrift: ....
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Publikation: The suppression of spontaneous face touch and resulting consequences on memory performance of high and low self-touching individuals. (Scientific Reports)

Autor:innen: Jente L. Spille, Martin Grunwald, Sven Martin & Stephanie M. Müller

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5.2. Eigenständigkeitserklärung

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