Testing the Effectiveness of Memory Suppression Strategies

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ABSTRACT

The current thesis compared the effectiveness of the direct (blocking memory) and substitution (thinking of something else) memory suppression strategies using the Think/No-Think (TNT) task. Eighty participants completed a TNT task using either the direct or substitution strategy during every occurrence of 12 repetitions for no-think word-pairs. Memory intrusions were reported by participants after each trial and their memory for both the think and no-think words were tested after all TNT trials were completed. A significant memory suppression effect was obtained for memory intrusions but not for either of the two memory tests (same-probe test, independent-probe test). The memory suppression effect also increased for memory intrusions reported by participants as the number of no-think repetitions increased across trials.

The memory strategy used by participants did not affect memory suppression (self-reported intrusions or memory test) suggesting that the two memory strategies are equally as effective for suppressing memories. However, future research is needed to support this conclusion as maintaining strategy compliance throughout a cognitively demanding Think/No-Think experiment was challenging for many of our participants. A failure to replicate a memory suppression effect for either of the memory tests also makes this conclusion more difficult to accept on the basis of the data collected in the current thesis.

Keywords: memory suppression, memory intrusions, memory repression, Think/No-Think task, memory suppression strategies

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Introduction

Since the mid-1990s, a debate termed the "memory wars" by Fredrick Crews in 1995 has raged in the realm of psychology. Memory wars refer to the disagreement between clinical and scientific communities on whether memories could be repressed or if repression is explained by false memories alone. Early on, scientific communities believed that false memories were the end-all, be-all for repression, while the clinical and therapeutic community maintained that individuals have the ability to repress memories. This debate emerged from early therapy and psychoanalysis efforts, sparked by theories from Johann Friedrich Herbart (Erdelyi, 2006) and popularized by Freud in the early 1900s as part of his psychoanalytic framework (Akhtar, 2020; Boag, 2006 and 2020; Frued, 1981). In his writings, Freud framed repression as an unconscious mechanism with the function of rejecting and keeping something out of consciousness. In some instances, such a mechanism could be used defensively to protect an individual from high-stress or traumatic events. The idea of repression became a cornerstone of Freud's psychoanalytic framework and was repopularized in the 1980s to the 90s.

Belief in this phenomenon of memories being repressed and retrieved later in life and the divide between scientific and clinical communities remains today; however, the scientific community is now divided on the issue as well (Otgaar et al., 2021; Patihis et al., 2014). Skeptics of repression referenced the lack of evidence for repressed memories in literature, with the 1990 review of repression in child sexual abuse by David Holmes at the forefront. Supporters of repressed memories pointed to the recovery of memories in therapeutic settings; however, skeptics pushed back, citing the use of guiding or suggestive therapy practices for such instances of recovered repressed memories (Yapko, 1994). In the case of these recovered memories, many

skeptics believed that they were nothing more than false memories, a memory recalled that never actually occurred, caused by high suggestibility or leading information (Loftus, 1974).

The focus of neuroscience and behavioral science research on this topic has allowed for clearer evidence in both directions of the discussion. The early steps of this research were towards developing from the broad and general idea of repression as an aspect of memory and forgetting to more clearly defined mechanisms, such as suppression and inhibition, for how individuals may repress memories or purposefully forget. Experimental research began pushing for the existence and definition of suppressed memories with the development of the directed forgetting paradigm by Robert and Elizabeth Bjork in 1989. The directed forgetting paradigm had participants view stimuli followed by an instruction to either remember or forget the stimuli presented. This paradigm showed that participants could intentionally forget a formed memory. Additionally, it was determined that the intentional forgetting seen was via retrieval inhibition (Bjork et al., 1998) and that this method of forgetting was an adaptive aspect of memory used in day-to-day life to reduce interference from unneeded information.

Further evidence of mechanisms that actively suppress memories has arisen since the onset of the memory wars with support for mechanisms such as a) retrieval-induced forgetting (RIF) in which favoring retrieval of one set of memories in turn suppresses and, over time, causes forgetting of competing memories (Anderson et al., 1994) and b) suppression-induced forgetting (SIF) which is a consequence of retrieval suppression in which individuals purposefully prevent retrieval of target memories, and leads to a reduction in the memory's valence and, eventually, forgetting (Anderson et al., 2004). The current paper focuses on the latter of these two mechanisms.

The processes leading to SIF have many similarities to motor response inhibition, which involves an individual engaging inhibitory control over motor actions to prevent the operant action from occurring. Retrieval suppression uses a similar form of inhibitory control but to prevent retrieval of a memory from occurring rather than a motor action. Retrieval suppression and SIF have been studied using the Think/No-Think (TNT) Paradigm, first introduced by Anderson and Greene in 2001. The TNT paradigm was developed to investigate memory retrieval stopping and, as such, was created by adapting from the go/no-go task, which investigates motor response inhibition (Gordon, 1983).

The TNT task involves three experimental phases: (1) The first is the *learning (memory encoding) phase,* where participants memorize a list of weakly associated word-pairs (e.g., INSECT-GRASS), where the left word is the cue word, and the right word is the target or response word for each word-pair. Participants must successfully recall a baseline (minimum) percent of these word-pairs before moving on to the next phase of the TNT task. Only after passing the baseline criterion for the learning phase could participants move on to the (2) second phase, *the Think/No-Think phase*. For this phase, the experimenter pre-assigned each word-pair to either a think, no-think, or baseline condition. For a think trial, the participant is instructed to recall the target word when the cue word for that word-pair is displayed. For a no-think trial, the participant is instructed to suppress the recall of the target word when the cue word is displayed. Baseline word pairs are not displayed in the Think/No-Think phase and are used as a baseline for initial learning in final memory tests. Before the full TNT phase, participants are generally given a set of practice trials containing both think and no-think trials to ensure a full understanding of task expectations.

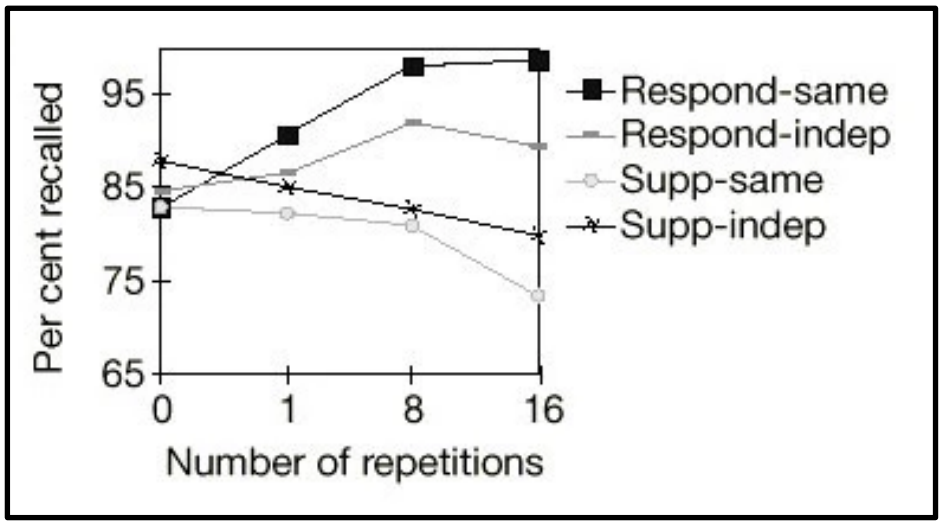
In Anderson and Green's original 2001 study, the participants were told which word-pairs would require retrieval and which would be suppressed via lists before the Think/No-Think trial phase. However, this approach was changed by Anderson and Green (2004), and the now-preferred method is to signal this information using different text colors for displaying the cue words. Think trials are indicated using a green text color for the cue word, and no-think trials are indicated using a red text color. Not only did Anderson and Green (2001) test for a trial type (think v. no-think) memory suppression effect, but they also varied the number of times each cue word was presented to the participant and, due to this, varied how often a specific target word was suppressed. The number of repetitions varied from zero (no rehearsal or suppression for these word-pairs) to one, eight, and sixteen repetitions throughout this phase. In the original 2001 study, the zero-repetition condition was considered the baseline. Filler word-pairs from the list of word-pairs shown to participants in the learning phase were also used to double the number of think trials, consistent with a majority (pre-potent) response for the go trials in the go/no-go task.

After the Think/No-Think phase, the participant is tested for their recall of the target words for each word-pair using two cued-recall memory tests, same-probe and independent-probe, in the (3) *recall (memory test) phase*. The same-probe (SP) test uses the previously seen cue words as prompts, in the same way, participants were tested in the first phase of word-pair learning (e.g., INSECT-____). The independent probe (IP) test cues retrieval of the target word with a semantic category that relates to the target word and includes the first letter of the target word to be recalled (e.g., YARD-G___). Anderson and Green created the IP test to distinguish memory suppression from memory interference in the no-think trials in 2004. If poorer recall

resulted in no-think trials on the IP test when using a unique cue (semantic category), this would suggest that memory suppression was occurring rather than memory interference.

Anderson and Green (2001) hypothesized that suppressing the recall of target words on no-think trials would negatively impact later recall from long-term memory due to inhibition of their memory activations. Poorer recall was found for both cued-recall tests when the no-think trials were compared with the think trials; additionally, no-think trials (suppression in Anderson's figure) had a lower recall rate and think trials had a higher recall rate than baseline word-pairs. Anderson and Green found a stronger memory suppression effect as the number of no-think repetitions increased, and we refer to this critical finding as the 'repetition effect.' These effects can be seen in Figure 1, taken from Anderson & Greene's 2001 study below.

Figure 1



Note. Average values across experiments from Anderson & Greene, 2001 for respond (think) and suppress (no-think) trials on same (SP) and indep. (IP) final memory tests.

Since these findings, intrusion ratings during the TNT phase were introduced. Intrusion ratings appear after each trial, regardless of type, and measure the self-reported amount of intrusions during the preceding trial. Intrusions are unwanted memories entering consciousness via retrieval meant to be suppressed. Participants rate intrusions on a 3-point scale ranging from

no intrusions to very frequent intrusions. Intrusion ratings were first introduced into Think/No-Think research in 2012 by Levy & Anderson as a measure for memory suppression on a trial-by-trial basis. Intrusion ratings were an adaptation of a trial-by-trial introspection method used in attention research (Levy & Anderson, 2012). Previous research has shown that successfully preventing an intrusion from occuring is correlated with later successful suppression-induced forgetting (SIF) on recall tasks (Hellerstedt et al., 2016; Levy & Anderson, 2012).

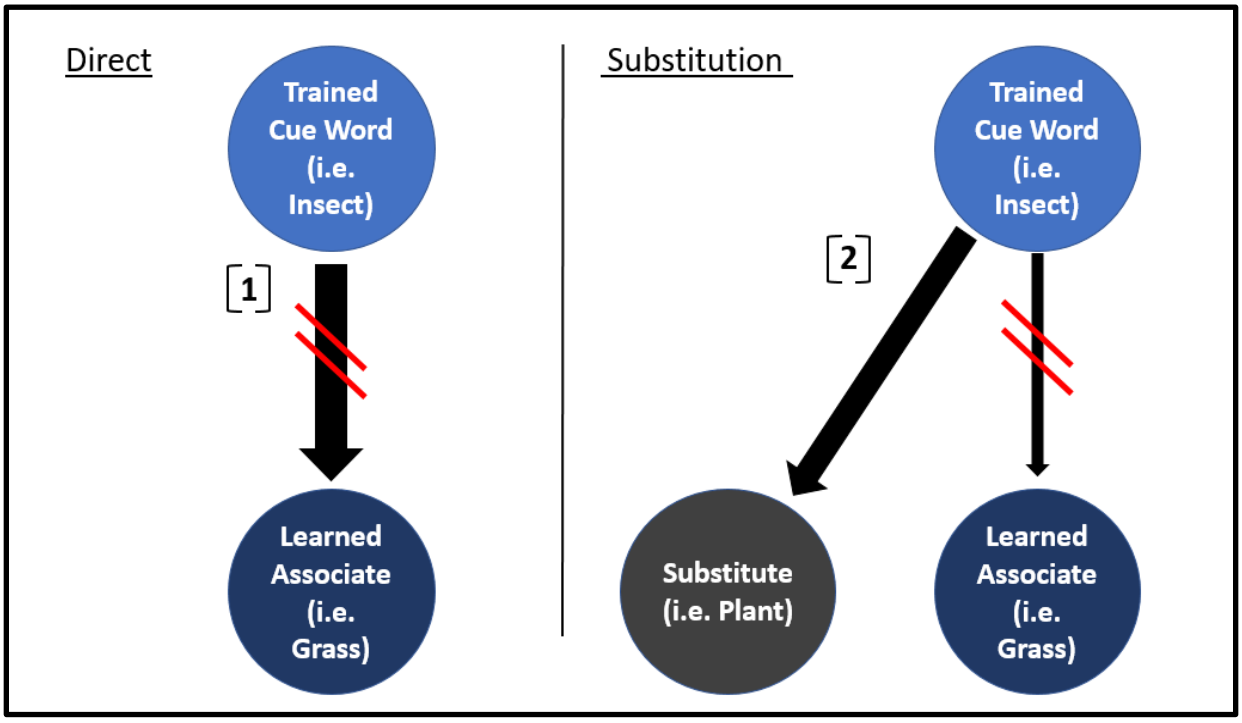
Additional support for Anderson and Green's memory suppression hypothesis comes from neuroimaging studies or neurological mechanism theory using the TNT paradigm (Anderson, 2003; Anderson et al., 2004; Benoit et al., 2015; Butler and James, 2010; Depue et al., 2007; Hu et al., 2017; Levy and Anderson 2012; Wang et al., 2015; Yan et al., 2022; Yang et al., 2021); for a review, see Anderson & Hulbert, 2021. These studies concluded that the TNT effect of suppression-induced forgetting was not caused by less memory rehearsal of words during no-think trials compared to think trials; instead, it was produced via increased activity found in the inhibitory control areas of the brain (prefrontal cortex, parietal cortex) during no-think trials. An increase in inhibitory brain activity was also matched with reduced activity in the memory-processing areas of the brain, such as the hippocampus, through inhibitory regulation via the right middle and right inferior frontal gyri (rMFG and rIFG) (Gagnepain et al., 2014) and the sensory-processing areas of the brain, such as the occipital cortex (Butler and James, 2010; Levy and Anderson, 2012). Specifically, it has been found that the dorsal anterior cingulate cortex (dACC) is initiated in response to unwanted memories and, in turn, initiates inhibitory control via the right dorsolateral prefrontal cortex (rDLPFC) on the hippocampus (Crespo-García et al., 2022). These findings highlight how important the TNT methodology has become for supporting the existence of memory suppression, specifically during the inhibition of intrusive or

unwanted memories, and provide evidence for a neurological inhibitory mechanism for suppression-induced forgetting.

Within the Think/No-Think task, two common inhibitory strategies can be employed to achieve the goal of suppression-induced forgetting. These strategies are that of direct suppression, in which participants simply keep their mind blank or force thoughts out of recollection during no-think trials, and substitution, which has a participant retrieve or recall competing memories rather than the target memory of a trial (Benoit & Anderson, 2012; Marsh & Anderson, 2022). These strategies have been shown to differ in their mechanisms for suppression, as can be seen in Figure 2 (Benoit & Anderson, 2012; Racsmány et al., 2012). Direct suppression produces memory suppression when the right dorsolateral prefrontal cortex (PFC) inhibits the hippocampus, which commonly initiates retrieval. This reduction of hippocampus activity impacts retrieval and consolidation of memories universally as seen by the occurrence of amnesic shadows, a reduction in recall for events occurring while an individual is suppressing a memory (Hulbert et al., 2016; Zhu & Wang, 2020). Substitution produces memory suppression through the engagement of the caudal prefrontal cortex and mid-ventrolateral prefrontal cortex regions (del Prete et al., 2012); however, it does not inhibit the hippocampus (Benoit & Anderson, 2012), rather brain regions activate to resolve the conflict between the produced substitute and a prior memory (Noreen et al., 2016). Additionally, substitution causes interference from the competition between substitutes and learned associates (see Figure 2) (Benoit & Anderson, 2012; Levy & Anderson, 2008). The retrieval of a substitute as a competitor has been shown to cause forgetting (Wimber et al., 2015) and providing a substitute to use during substitution has been shown to aid suppression (Hertel & Calcaterra, 2005);

however, substitution has been shown to lack suppression when participants are given non-semantic cues (Bergstrom et al., 2007).

Figure 2



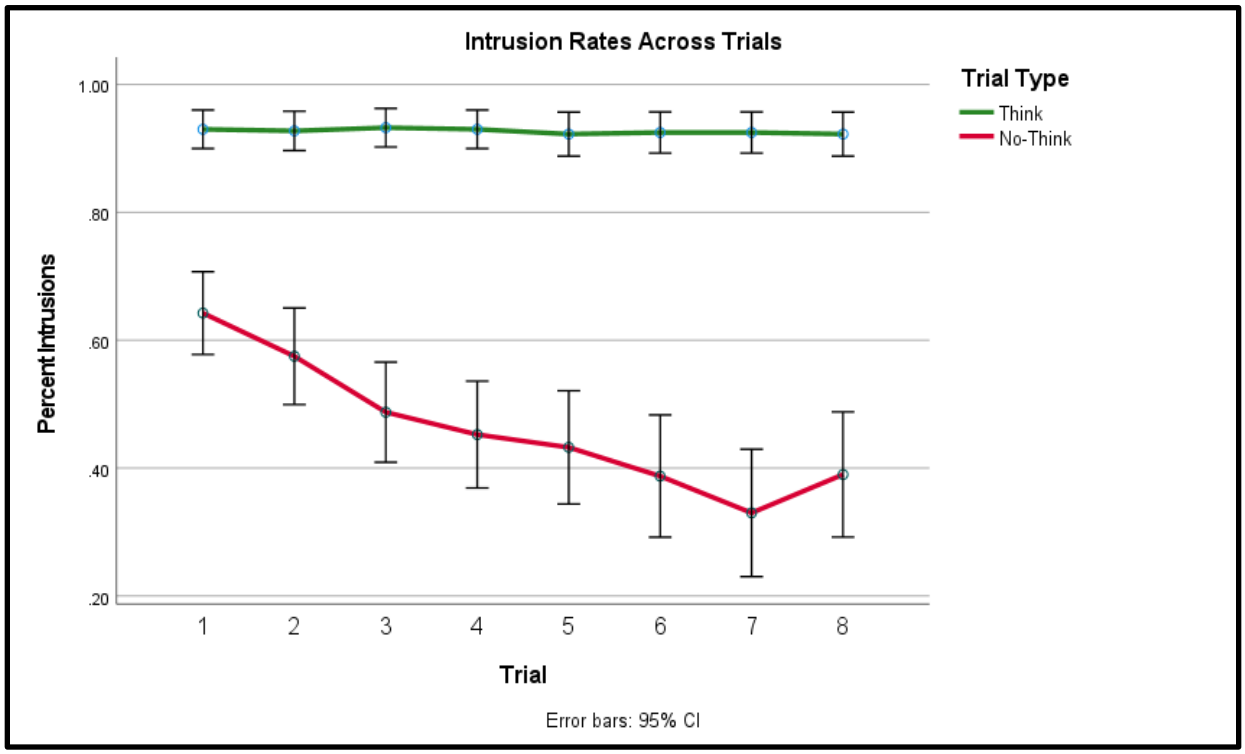
On the left of Figure 2, a direct strategy pathway is shown with (1) suppression of the retrieval for a learned associate displayed as red lines across an arrow representing retrieval. On the right of Figure 2, a substitution pathway is shown, displaying (2) an increase in the strength of the connection between the trained cue and a substitute with a decrease in the connection between the trained cue and the learned associate via competition between the substitute and learned associate, this competition is resolved over time by repeated favoring of the preferred substitute. Research using the directed forgetting (DF) paradigm has given further support for different strategy mechanisms, as performance on a Stop Signal task, specifically used to measure inhibition, was only correlated with the success of direct strategy and not with a substitution strategy (Hubbard & Sahakyan, 2023).

Regardless of the strategy employed, SIF requires compliance with instructions in order to occur (Liu et al., 2021). Due to this, determining task compliance is necessary to gauge the effectiveness of the TNT task on an individual basis. To rectify this, post-experiment questionnaires to get a self-report measure of task compliance have gained traction. Post-experiment questionnaires ask questions to determine the prevalence of the use of either direct or substitution strategies, adherence to overall TNT task instructions, and to gauge final memory test expectancy. These questions aim to determine if individual participants followed instructions and performed the TNT task correctly and how much of each strategy an individual believes they used across the experiment. In analysis, these measures can be used as exclusion criteria to filter out individuals who may have not shown SIF due to noncompliance. Additionally, questions looking at strategy use can be used to determine how difficult individuals found a strategy. If a participant scores low on compliance on their instructed strategy or scores high on a strategy they were not instructed to use, it can be said that they may have had difficulty with strategy use.

As more research investigated inhibitory mechanisms contributing to SIF, multiple studies showed inhibition fatigue within no-think intrusion ratings from the TNT phase of the TNT task (Anderson & Huddleston, 2011; Rogers, 2020; van Schie & Anderson, 2017). Inhibition fatigue is noted as a reduction in the no-think effect normally seen in the TNT paradigm and can be seen in a rise of reported intrusions on later no-think trials during the TNT phase or final memory test results across repetitions. Inhibition fatigue is hypothesized to be caused by task or cognitive fatigue over time. This can be seen in previous research we conducted, in which the negative slope of no-think intrusion rates flattened at six repetitions and followed an upward trend to eight repetitions (Rogers, 2020) (Figure 3). Inhibition fatigue in the TNT paradigm was supported by previous literature when sustained inhibitory control can

caused deficits in memory suppression due to fatigue (van Schie & Anderson, 2017), sustained inhibition (Lee, Lee & Tsai, 2007), or high cognitive demand (Noreen & de Fockert, 2017) when using direct suppression. Notably, Noreen & de Fockert (2017) found that high cognitive load specifically reduced the ability to inhibit, seen in a reduction of SIF during independent-probe tests, but did not impact the effects of interference on later reduced recall, as same-probe tests still presented with reduced recall for no-think items.

Figure 3



Note. Data for this figure is from pilot data for the current experiment using shortened TNT methods.

Inhibition fatigue is seen in multiple areas of research concerning inhibitory control. Response inhibition fatigue or mental fatigue is frequently seen in the literature using the go/no-go task and can be purposefully induced via increased cognitive load or increased overall task time (Guo et al., 2018; Kato et al., 2009). In go/no-go literature examining ERPs, it was shown that available cognitive resources reduce as an experiment goes on, and, as cognitive resources are used up, inhibition of responses can be slowed, specifically a slowing of conflict detection

between mental representations of go and no-go stimuli (Guo et al., 2018). Go/No-Go literature has shown deterioration of cognitive control across experiment time via reduction of dopamine systems within the anterior cingulate cortex (Lorist et al., 2005). Additionally, research using the go/no-go task has shown mental fatigue to cause difficulty in response preparation, attention focusing, and ignoring unnecessary information (Boksem et al., 2005; Boksem et al., 2006; Boksem & Tops, 2008; van Linden & Eling, 2006). The inhibitory pathways used in motor and behavioral response inhibition are quite similar, if not the same, as those used in memory retrieval inhibition (Aron et al., 2004; Castiglione et al., 2019; Castiglione & Aron, 2021; Depue et al., 2010; Depue et al., 2012; Depue et al., 2016; Levy & Anderson, 2008, Mecklinger et al., 2009; Wessel & Aron, 2014). Several researchers have proposed that the network for inhibitory control is universal across inhibitory actions, with different inhibitory actions utilizing aspects of the same network (Depue et al., 2016; Guo et al., 2018: Levy & Anderson, 2008; Wessel & Aron, 2014).

The TNT paradigm has a longer task time, higher resource need, and lower applicability in the current digital age compared to the other memory suppression paradigms, such as the directed forgetting paradigm or selective retrieval tasks. The current study will use a modified version of the TNT task, which eliminates the vast majority of experimenter-participant interaction, uses typed responses with which participants can submit answers as soon as they are complete, and takes approximately 34 to 42 minutes, depending on the number of cycles needed to reach a 50% baseline. This shortened methodology was shown to replicate repetition effects from previous literature via pilot data (Figure 3). In our previous research using a standard TNT task (Rogers, 2020), participants took on average 62 minutes. Given the replication of previous research using a shortened version of the TNT paradigm in pilot data and the reduction of

average task duration by 20 to 28 minutes, we hope we can remove task time from potential parameters impacting mental and inhibition fatigue.

The current study proposes that, given differing mechanisms in direct and substitution strategies, inhibition fatigue may differ across strategy use. Support for this hypothesis of separate fatigue of mechanisms can be seen in the study by Noreen & Fockert in 2020, in which they found participants could still prevent unwanted memories from being recalled when they switched strategies. Direct suppression may have an earlier onset or stronger impact of inhibition fatigue compared to that of memory suppression via substitution. This hypothesis stems from the support for substitution employing both top-down inhibition similar to what is seen in direct suppression, but through separate pathways, and interference via competing memory traces of the substitute thoughts during no-think trials. With the additional pathway and method for suppression seen in substitution strategies, we believe individuals may be able to activate inhibitory mechanisms more before inhibition fatigue becomes present or that the non-fatiguing interference will counteract the inhibition fatigue seen and thus show weaker inhibition fatigue compared to direct suppression.

With the current study, we aim to determine the differences in strategy effectiveness by examining inhibition fatigue in both direct and substitution strategies, the two most commonly employed strategies for memory suppression. We believe this research is both a current gap in memory suppression literature and a highly necessary gap to fill. Previous research has shown that certain groups, such as individuals with ADHD (Depue et al., 2010; Storm & White, 2010), PTSD (Steward et al., 2020; Sullivan et al., 2019; Waldhauser et al., 2018), alcohol dependence (Nemeth et al., 2014), borderline personality disorder (Sala et al., 2009), anxiety (Fawcett et al., 2015; Quaedflieg et al., 2020; Waldhauser et al., 2011) or depression (Dieler et al., 2012; Hertel

& Gerstle, 2003; Hertel & Maham, 2007; Noreen & Ridout, 2016; Noreen et al., 2020; Sacchet et al., 2017; Yang et al., 2020; Zhang et al., 2016) have memory suppression deficits. Intrusive thoughts and deficits in memory suppression have been proposed as a hallmark of many psychological disorders overall (Costanzi et al., 2021; Strammacia et al., 2021). Additionally, it was found that older adults showed deficits in memory suppression, and the difficulty was in the implementation of a strategy effectively (Murray et al., 2015). Many groups with below-average memory suppression capabilities are at-risk or experience recurrent involuntary memories (Sullivan et al., 2019). If the pitfalls and effectiveness of memory suppression strategies can be determined, we believe future research could implement actions such as strategy switching or strategy-use training to circumvent deficiencies in memory suppression.

Methods

Participants

A total of 92 individuals participated in the current experiment. All participants were undergraduate psychology students attending the College of William and Mary. Students were recruited through the SONA system used at the college. Forty-seven (~58%) of the participants were male identifying and thirty-three (~42%) were female-identifying. The participants had a mean age of 19.19 years. Participants were given course credit as compensation for participating in this research and provided informed consent before participating. An a priori within-between repeated measures ANOVA analysis using G*Power 3.1.9 using an effect size of .25 based on our pilot data and past literature, a power of .9, an alpha of .05, and a .2 correlation among repeated measures estimated the need for forty participants to achieve a power of .91. Due to the possibility of analyses using exclusion criteria, we collected data until eighty participants had

passed learning criteria. The college's ethics committee approved the research conducted in this thesis.

Pilot Data

The current study implemented a shortened version of the Think/No-Think task in hopes of reducing task time, resources used, and demand characteristics. Pilot research was conducted to determine if the shortened-TNT task replicated the reduction of no-think intrusion ratings. Our pilot study tested whether a Think/No-Think task using only 38 word-pairs (ten baseline, ten think, ten no-think, and ten filler), allowing typed input rather than verbal, and with no practice trials could produce similar results as previous literature; specifically, if the repetition effect was reproduced, as this is the main area of concern for the current study.

Pilot data was collected from 40 participants of which 30 were female-identifying and 10 were male-identifying. The sample had a mean age of 18.9 years. A 2 (Trial Type: think v no-think) X 8 (Trials: Number of Times each word-pair was repeated) within-subject ANOVA had significant trial ($F(1,39) = 18.47$, $p < .001$, $\eta^2_p = .321$), trial type ($F(1,39) = 122.80$, $p < .001$, $\eta^2_p = .759$), and trial by trial type interactions ($F(1,39) = 16.38$, $p < .001$, $\eta^2_p = .296$) with an effect size of $\eta 2 = .296$. Additionally, an ANOVA looking at change across no-think trials showed a significant repetition effect ($F(1,39) = 17.778$, $p < .001$, $\eta^2_p = .313$), as seen by the decrease of no-think intrusions across trial repetitions in Figure 2, consistent with previous literature and an effect size of $\eta 2 = .313$. In the current study, given replication of all the major intrusion rating effects, we will use the shortened TNT methodology, described in detail below, as well as use the effect sizes from pilot data for post hoc power analyses.

Think/No-Think Task

Participants took part in a modified version of the Think/No-Think task. The Think/No-Think Task involved three phases: The learning phase, the Think/No-Think (TNT) phase, and the recall phase. Data from each phase was automatically collected through the PsychoPy program and all stimuli's order and conditions were randomized within phases and between participants. Stimuli consisted of one of three 38-word pair lists in the form of a left-hand cue word and a right-hand response word (i.e., GRASS - INSECT). Of the 38-word pairs, ten were assigned as think, ten as no-think, ten as baseline, and eight as filler word pairs. Thirty of the 38-word pairs were randomly pre-assigned as either a think, no-think, or baseline word pair for each of the three word-pair lists participants were assigned to. The eight remaining word pairs were used as filler word pairs and held constant across lists. All word pairs and their conditions by list can be found in Appendix A. Participants were counterbalanced across word lists.

Learning Phase.

Participants were presented with the 38-word pairs and instructed to learn them so, if the left word was shown, they could recall the right word. Each word pair was presented for four seconds and preceded by a 400ms fixation cross. Following the presentation of all 38-word pairs, participants were evaluated on their recall of all word pairs. The left word of each pair was presented in the center of the screen for up to eight seconds. During that time, participants were instructed to type the target word previously paired with the cue word shown on screen. After confirming their answer, the correct feedback was given via presentation of the word-pairing for two seconds. Participant recall was evaluated based on the percentage of think, no-think, and baseline word pairs answered correctly. To move to the TNT phase, a participant was required to reach or surpass a 50% recall rate of the 30 measured word pairs. Participants were given up to

three attempts to reach the 50% criteria to move on in the experiment; however, if the criteria were not reached in those three attempts, their experiment was ended and data excluded.

TNT Phase.

Participants were first instructed on how to approach this phase of the experiment via several sets of instructions. These instructions informed the participant that the left word of previous word pairs would be shown in either green or red. If the left word was shown in green, the participant was to actively attempt to recall the word previously paired with the displayed word. If the left word was shown in red, participants were instructed one of two ways. If the participant was in the direct suppression group, they were instructed to actively prevent the word previously paired with the displayed word from being recalled by keeping their mind blank and not thinking of anything else. Participants in the substitution suppression group were instructed to prevent the paired word from coming to mind by thinking of something else during the trial. Additionally, participants were informed that, after each word presentation, a three-point scale would appear. The participant was to select how much an intrusion occurred during the previous word, with an intrusion being defined as a thought relating to the word pairing coming to mind. They selected either '1' as no intrusion, '2' as some intrusion, or '3' as a complete intrusion. After instruction, participants began the TNT phase.

The TNT phase consisted of twelve repetitions of each think cue-word in green and no-think cue-word in red. Baseline word pairs were not presented in this phase. All words were presented in groupings of two repetitions each, and these groupings were randomized and presented six times; such that for a word to be shown a third time, all other words must have already been shown twice; for a word to be shown a fifth time all other words must have been shown four times, etc. Filler word pairs were displayed in green to act as think trials to raise the

percentage of think trials to ~65%, as seen in previous literature (Anderson and Greene, 2001; Anderson et al., 2004; Gordon, 1983). As such, 336 trials total were seen, with 216 of the trials being think-instructed trials. Each word appeared on screen for four seconds, preceded by a 400ms fixation cross. After each word presentation, the 3-point scale was displayed and would remain on-screen until the participant gave input. Upon input, the next fixation cross and word pair presentation was immediately given. Once data was collected, the 3-point scale was converted to a dichotomous scale of either an 'intrusion' or a 'non-intrusion' trial. This was recoded by having any trial with partial (2) or full (3) intrusion considered 'intrusion' trials, while trials with no (1) intrusion were considered 'non-intrusion' trials; consistent with previous literature (Castiglione & Aron, 2021; Levy & Anderson, 2012; van Schie & Anderson, 2017)

Recall Phase.

Participants were given two memory recall tasks to evaluate recall of the think and no-think word pairs after administration of the TNT phase. The two memory recall tests were a same-probe (SP) and an independent-probe (IP) test. The SP test involved displaying the target word for each word pair for up to eight seconds, followed by a 400ms fixation cross. During the eight seconds, the participant was instructed to type the remembered target word in response to the displayed cue word, regardless of whether the cue word it had been paired with was part of a think or no-think trial during the TNT phase. During the IP test, a semantic category for the cue word and the first letter of the target word for each word pair was presented. For example, PLANT - G___ was displayed for the word-pair BUG - GRASS. Each category and first letter pair were shown for up to eight seconds and preceded by a 400ms fixation cross. Participants were instructed to input a previously learned target word that matched the category and began with the letter displayed. Test order was counterbalanced across participants. Final memory test

recall rates were converted to baseline-centered values for additional analysis. Baseline-centered values were calculated by subtracting baseline recall in same-probe and independent-probe tests from think and no-think recall, for each test respectively.

Post-Experiment Questionnaire

Due to the manipulation of strategy, a post-experiment questionnaire based on prior literature (Hertel & Calcaterra, 2005; Liu et al., 2021) was included to measure participant's overall compliance with the Think/No-Think task as well as the use of both direct and substitution strategies. The questionnaire consisted of five questions on a zero to four scale (0-Never, 1-Rarely, 2-Sometimes, 3-Frequently, 4-Very Frequently) based on questions used in previous literature (Liu et al., 2021). The first question measured the frequency of use of a substitution strategy. The second question measured the frequency of use of a direct strategy. The last three questions each measured an aspect of compliance with overall TNT task instructions; therefore, participants were rated on a 0-12 scale for overall compliance, zero being high compliance and twelve being low compliance. Additionally, we administered a three-point scale of "Yes"," No", and "Unsure" taken from previous literature (Hertel & Calcaterra, 2005) to measure test expectancy. The full questionnaire can be found in Appendix B.

Procedure

Participants were told that all instructions and information would be displayed on an X" x Y" screen for the experiment and that the door would be closed to prevent interruption. Word pairs were presented in the center of the screen with size 0.1 letter height (equivalent to 10% of the screen height or ___ inches) in Open Sans font. Participants were randomly assigned to one of three word-pair lists (List 1, 2, or 3, see Appendix A), the order of final recall tests they would receive (Same Probe First or Independent Probe First), and the strategy they would be instructed to use (Substitution or Direct); each was counterbalanced. Strategy was manipulated by the

instructions given to participants prior to the Think/No-Think phase, described below. Once they completed the study, participants received credit for their participation. They were sent an email containing a debrief of the experiment and an email to contact experimenters for any questions. This experiment was administered using PsychoPy v2021.2.3 on Windows 10.

Results

Ninety-two participants took part in the current experiment; however, eighty participants reached or surpassed the 50% learning criterion within three learning phases. Sample statistics and analyses will only use data from the eighty participants that reached or surpassed the learning criterion. This sample had a mean age of 19.19 years (STD = 1.264) and was made up of 58.8% (47) male-identifying individuals. This sample had individuals counterbalanced across lists (List 1: n=28, List 2: n=26, List 3: n=26), test order (SP 1st: n=40, IP 1st: n=40), and strategy instruction (Direct: n=38, Substitution: n=42). Additionally, 51 of the participants (63.7%) reached the 50% baseline criterion in one cycle of the learning phase, 21 (26.3%) needed two cycles, and 8 (10%) needed three cycles. On average, participants needed 1.54 cycles to reach the 50% baseline criterion. There were no significant differences in age, gender, lists, test order, cycles to meet the learning criterion or compliance to TNT instructions between strategy groups.

Previous research (Liu et al., 2021) suggests that compliance to the TNT instructions can be an issue in TNT experiments. Compliance was measured using three separate questions and the sum of responses to these questions was used as a measure of TNT compliance, as was done in Liu et al., 2021. Scores ranged from 0 (max compliance) to 12 (very poor compliance) with a mean of 6.06 and a standard deviation of 2.58. However, when this compliance score was

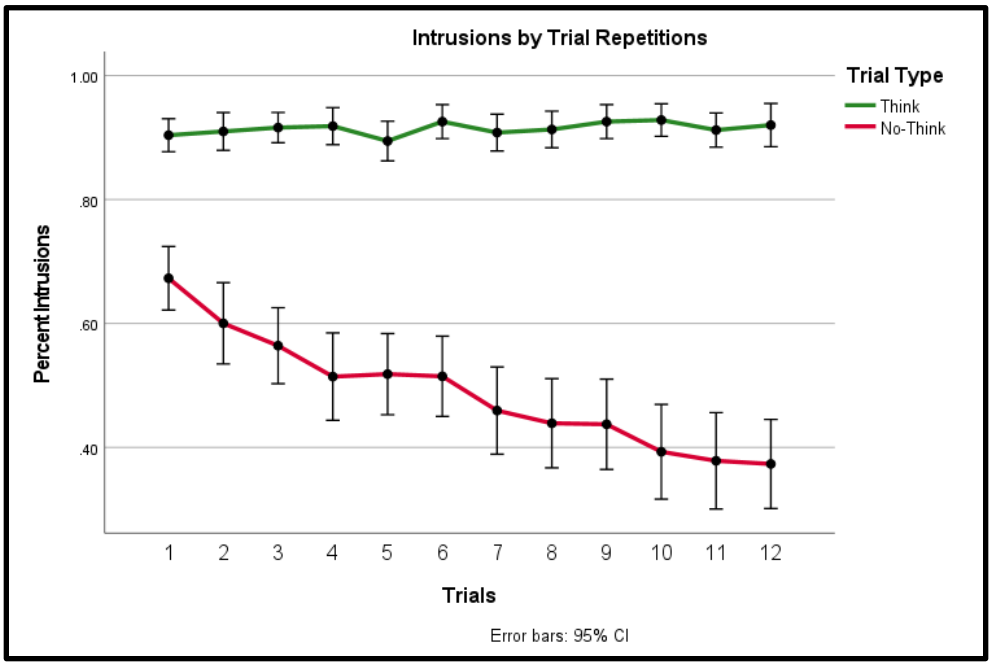
included as a covariate in ANCOVA analyses the compliance measure did not produce any significant effects and so these results will not be reported here.

Participants in the current experiment were required to follow a specific memory suppression strategy for each of the 120 no-think trials in the TNT phase. Some participants struggled to comply with this request with 5 of the 35 Direct group reporting that they never or rarely blocked words and 5 of the 42 Substitution group reporting they never or rarely thought of something else. The statistical analysis that follows was conducted again after removing these participants from the data analyzed, but removing these participants did not affect any of the significant results obtained, so these analyses will ne be reported here.

A three-way Strategy (Direct, Substitution) X Type of trial (think, no-think) X Trials (1-12) ANOVA was conducted for memory intrusions reported by participants. A significant main effect was obtained for trial type, $F(1,79) = 161.90$, $p < .001$, $\eta^2_p = .675$ as would be expected when comparing intentional intrusions (think trials) versus unintentional intrusions (no-think trials). A significant effect was obtained when increasing the number of repeated trials, $F(11,79) = 16.831$, $p < .001$, $\eta^2_p = .177$, and the interaction of trial type by trials was also significant, $F(11,79) = 17.287$, $p < .001$, $\eta^2_p = .181$. This interaction is displayed in Figure 3. and reveals that the memory suppression effect increased with more repeats of no-think words. Trend analysis of the no-think data revealed significant linear, quadratic, and cubic trends that suggest the memory suppression effect was not constant throughout the repeated trials. The effect appears strongest for the early repeats and starts to plateau as the repeats reach their maximum of 12 repeats.

Figure 3

Two-way interaction, type of trial x trials.



Two-way Strategy group X Trial type ANOVAs were conducted for the two memory tests. Overall memory performance for the target words was very good for the think words (SP test M = 92%; SD = 10% and IP test M = 84%; SD = 16%) and the no-think words (SP test M = 90%; SD = 13% and IP test M = 82%; SD = 16%).. The results of these tests were not significant, p>.05. This result is somewhat surprising given he average memory intrusion rate across all twelve repeated no-think trials was positively correlated with SP recall of the no-think words $r(78) = .20$, $p<.05$).

Discussion

Participants in the current study were separated into two groups, direct and substitution, based on the memory suppression strategy they were instructed to use throughout the TNT trials. Self-reported memory intrusions on no-think trials decreased with repeated trials but this effect did not differ between the two strategy groups; providing tentative evidence that the different strategies do not differ in memory suppression effectiveness with respect to intrusions occurring

while performing memory retrieval inhibition. Although a significant correlation was found for the suppression effect for memory intrusions and later recall of the no-think words, the current study was unable to show a memory suppression effect for either the same-probe (SP) or independent probe (IP) tests. Consequently, any conclusions regarding the effectiveness of the memory suppression strategies for producing suppression-induced forgetting (SIF) can not be made; however, we will discuss how future research can expand on the idea of strategy differences.

The major area of intrigue for the current study is the lack of strategy differences on no-think intrusion rates across trials. We hypothesized that direct strategies would show inhibition fatigue earlier on in trials due to the lack of support from interference that substitution strategies can produce. While the current study showed significant quadratic trends in no-think trials for both direct and substitution strategies, indicating some fashion of inhibition fatigue; there were no significant differences between strategy groups. The lack of differences between strategies could imply that there is in fact no difference in effectiveness; however, given the noted differences in how direct and substitution strategies achieve suppression-induced forgetting (SIF) effects, it is rather unlikely they have equal effectiveness on all measures of change in the Think/No-Think paradigm.

A likely reasoning for the lack of strategy difference would be non-compliance with strategy instructions; however, we found that, even with the most severe non-compliers excluded from analyses, strategies showed no differences in any of our statistical test. An alternative hypothesis for our results is measurement error or practices. The main issue could be how the current study attempted to induce fatigue effects. Induction of fatigue effects may be better done by more direct methods like lengthening trial duration (van Schie & Anderson, 2017) or

preceding the TNT task with another task that is high in cognitive resource use. This could be further explored by having trial length be a varying condition for no-think pairs or varying the (time between trials). Additionally, adding incentives in the form of promised payment upon completed study participation could help reduce confounding factors for reduced intrusion decrease in no-think intrusion ratings, such as loss of motivation. Another potential solution that can both prevent inattention and produce fatigue would be to have participants complete a task between sets of trials or individual trials during the TNT phase of the experiment while using strategy as a condition. A potential task to have participants perform in-between TNT trials would be a Stroop task, as the Stroop task could decrease inattention, promote further fatigue of inhibition mechanisms, and be capable of measuring inhibition fatigue themselves by logging errors on the task. Another that was previously used in literature was an n-back task, which has shown reduction of inhibition effects on final memory tests (Noreen & de Fockert, 2017).

Another plausible explanation for no strategy differences could be individual differences in strategy use. Individual differences in ability to perform SIF have already been widely noted in literature. One aspect that has not been investigated in current TNT literature is individual differences for strategy use. The current study found that participants reported using both strategies regardless of the strategy instructions they were given. An explanation for this could be individual differences in preferred strategies for preventing intrusive thoughts. Individuals may find one strategy more effective overall and revert to their preferred or more practiced strategy once they find the instructed strategy ineffective. Additionally, it is possible that restricting intrusive memory prevention to only one strategy is not effective in the first place. Individuals may use both strategies for different situations, possibly switching between strategies once they find them fatiguing and ineffective.

This raise the possibility that SIF is not achieved via one strategy or the other, but through a more dynamic and fluid strategy-switching. This aligns with neurological research involving the TNT paradigm showing that, even when retained to a single strategy, aspects of the other strategy are seen. When an individual is using a direct strategy, substitution does not stop occurring, but is not the primary initiator of SIF; similarly, to perform substitution, some amount of direct suppression is needed for the substitute to outweigh an original memory during retrieval for SIF to occur (Marsh & Anderson, 2022). Future research could investigate dynamic strategy use with different forms of brain imaging during no-think trials as well as could have participants report how suppression was achieved on a trial-by-trial basis.

Methodology was confirmed by pilot research showing replication of expected TNT effects in both intrusion ratings and final memory tests, however, the pilot did not manipulate strategy use. As such, the changes in results for final memory tests could be due to the addition of strategy use as a manipulation. However, changes in intrusion ratings were still replicated and previous literature has shown that a decrease in no-think intrusions is predictive of TNT effects on final memory tests. Therefore, it comes to question why a strategy use manipulation would impact final memory test results but not intrusion rating results. We propose that the previously mentioned strategy switching or reversion to a preferred strategy can explain this as well. In the current studies intrusion ratings results, both quadratic and cubic trends were seen for each strategy. Our original hypothesis was that these trends would point to inhibition fatigue on later trials, but these trends appeared in mid-trials between four and eight graphically. We propose that these plateaus and rises in no-think intrusions may have been caused by mid-task strategy switching by participants, supported by the reporting of some use of each. If true, it could be posited that final memory recall tests did not show no-think effects due to mid-task strategy

switching. Future research should look at the effects of switching strategy on SIF for same- and independent-probe tests.

Appendix A

Post-Experiment Questionnaire

In the word-pair learning phase, the word pairs consisted of a left (CUE) word and a right (RESPONSE) word. In the main phase of the experiment, you were asked to NOT THINK about the response word when the cue word was displayed in RED.

During this phase, how frequently did you:

1. **think about OTHER words associated with the cue word while the cue word was on screen to keep yourself from recalling the response word.**

Never	Rarely	Sometimes	Frequently	Very Frequently
0	1	2	3	4

2. **keep your mind BLANK or FOCUS on the cue word while the cue word was on screen to keep yourself from recalling the response word.**

Never	Rarely	Sometimes	Frequently	Very Frequently
0	1	2	3	4

3. **make sure you still remembered the response word first, and then tried not to think of this response word while the cue word was displayed.**

Never	Rarely	Sometimes	Frequently	Very Frequently
0	1	2	3	4

4. **try not to think of the response word while the cue word was displayed, but then after the cue word stopped being displayed, quickly checked that you could still remember the response word.**

Never	Rarely	Sometimes	Frequently	Very Frequently
0	1	2	3	4

5. **stop yourself from typing the response word while the cue word was displayed but kept repeating the response word to yourself so as not to forget it.**

Never	Rarely	Sometimes	Frequently	Very Frequently
0	1	2	3	4

When we instructed you to not think about the response word that was paired with a specific cue word displayed in RED, did you suspect at the time that you would later be tested on your memory for these response words?

a. No
b. Yes
c. Unsure

Appendix B

Word Pair Lists

	List 1	List 2	List 3	Filler Word Pairs (Same Across All Lists)
Think Word Pair 1	ACCIDENT - SNOW	CANDLE - WINE	GLOW - GHOST	CRACK - LOBSTER
Think Word Pair 2	AVENUE - MILE	CRUMB - TOASTER	BEACH - AFRICA	LIBERTY - EAGLE
Think Word Pair 3	BREATH - NOSE	DECAY - CARBON	JOURNEY - PANTS	NEEDLE - DOCTOR
Think Word Pair 4	CHOIR - GUITAR	HUG - ROSE	OFFICER - BLUE	PET - MOUSE
Think Word Pair 5	DIET - CREAM	MIXTURE - JAR	TAPE - RADIO	PIPE - WRENCH
Think Word Pair 6	DOUGH - SALT	NAIL - PICTURE	STUMBLE - CLOWN	RELAX - BED
Think Word Pair 7	HIVE - HEXAGON	PICNIC - HILL	JAW - GUM	SOIL - TOMATO
Think Word Pair 8	LEAP - BALLET	POLISH - DIAMOND	ANTLER - KNIFE	SURPRISE - SNAKE
Think Word Pair 9	REMOVE - CANCER	RUG - WOOL	BROOM - HOUSE	
Think Word Pair 10	VITAMIN - LEMON	STEAM - TRAIN	CRADLE - PARENT	
No-Think Word Pair 1	CANDLE - WINE	GLOW - GHOST	ACCIDENT - SNOW	
No-Think Word Pair 2	CRUMB - TOASTER	BEACH - AFRICA	AVENUE - MILE	
No-Think Word Pair 3	DECAY - CARBON	JOURNEY - PANTS	BREATH - NOSE	
No-Think Word Pair 4	HUG - ROSE	OFFICER - BLUE	CHOIR - GUITAR	
No-Think Word Pair 5	MIXTURE - JAR	TAPE - RADIO	DIET - CREAM	
No-Think Word Pair 6	NAIL - PICTURE	STUMBLE - CLOWN	DOUGH - SALT	
No-Think Word Pair 7	PICNIC - HILL	JAW - GUM	HIVE - HEXAGON	
No-Think Word Pair 8	POLISH - DIAMOND	ANTLER - KNIFE	LEAP - BALLET	
No-Think Word Pair 9	RUG - WOOL	BROOM - HOUSE	REMOVE - CANCER	
No-Think Word Pair 10	STEAM - TRAIN	CRADLE - PARENT	VITAMIN - LEMON	
Baseline Word Pair 1	GLOW - GHOST	ACCIDENT - SNOW	CANDLE - WINE	
Baseline Word Pair 2	BEACH - AFRICA	AVENUE - MILE	CRUMB - TOASTER	
Baseline Word Pair 3	JOURNEY - PANTS	BREATH - NOSE	DECAY - CARBON	
Baseline Word Pair 4	OFFICER - BLUE	CHOIR - GUITAR	HUG - ROSE	
Baseline Word Pair 5	TAPE - RADIO	DIET - CREAM	MIXTURE - JAR	
Baseline Word Pair 6	STUMBLE - CLOWN	DOUGH - SALT	NAIL - PICTURE	
Baseline Word Pair 7	JAW - GUM	HIVE - HEXAGON	PICNIC - HILL	
Baseline Word Pair 8	ANTLER - KNIFE	LEAP - BALLET	POLISH - DIAMOND	
Baseline Word Pair 9	BROOM - HOUSE	REMOVE - CANCER	RUG - WOOL	
Baseline Word Pair 10	CRADLE - PARENT	VITAMIN - LEMON	STEAM - TRAIN	

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