Vocal Control: Is It Susceptible to the Negative Effects of Self-Regulatory Depletion?

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Summary: Objectives. Self-regulation (SR) relies on the capacity to modify behavior. This capacity may diminish with use and result in self-regulatory depletion (SRD), or the reduced ability to engage in future SR efforts. If the SRD effect applies to vocal behavior, it may hinder success during behavioral voice treatment. Thus, this proof-of-concept study sought to determine whether SRD affects vocal behavior change and if so, whether it can be repaired by an intervention meant to replete SR resources.

Methods. One hundred four women without voice disorders were randomized into groups that performed either (1) a high-SR writing task followed by a high-SR voice task; (2) a low-SR writing task followed by a high-SR voice task; or (3) a high-SR writing task followed by a relaxation intervention and a high-SR voice task. The high-SR voice tasks in all groups involved suppression of the Lombard effect during reading and free speech.

Results. The low-SR group suppressed the Lombard effect to a greater extent than the high-SR group and high-SR-plus-relaxation group on the free speech task. There were no significant group differences on the reading task.

Conclusions. Findings suggest that SRD may present challenges to vocal behavior modification during free speech but not reading. Furthermore, relaxation did not significantly replete self-regulatory resources for vocal modification during free speech. Findings may highlight potential considerations for voice treatment and assessment and support the need for future research focusing on effective methods to test self-regulatory capacity and replete self-regulatory resources in voice patients.

Key Words: Self-regulatory depletion–Self-regulatory repletion–Lombard effect–Voice therapy.

Voice treatment may be defined as physical adjustments of the respiratory, laryngeal, and supralaryngeal musculature to achieve changes in vocal quality, pitch, and/or loudness.[1–3] This definition implies that individuals with functional voice problems are engaging in inefficient and uncoordinated phonation with little, if any, awareness.[4]

Patients in voice therapy are asked to make conscious changes to their phonation. To do this, they use self-regulation (SR). SR is defined as effort, exerted by the self, to modify or control cognitions, emotions, or outward behavior.[5] SR is conceptualized as relying on a limited resource or strength which, when weakened through use, can lead to what is known as self-regulatory depletion (SRD).[6] SR and SRD have been demonstrated in a broad range of everyday behaviors, from decision making to working with others to perform a task. In a typical SR experiment, the participant completes an initial task that has either a high or a low self-regulatory demand and then completes a second task that has a high self-regulatory demand. SRD is detected when performance on the second task declines after the completion of an initial high self-regulatory task versus a low self-regulatory task. For example, when university students were directed to eat only radishes in the presence of chocolate cookies and candies, they performed more poorly on a subsequent self-regulatory task (complex problem solving), in comparison to their peers who were allowed to eat these treats.[7] The healthy-eating group had depleted their self-regulatory resources by initially resisting temptation and thus had fewer resources for the subsequent problem-solving task.

There is ample evidence that SRD crosses task modalities, so that exerting SR on one task results in degraded performance on a subsequent unrelated self-regulatory task.[6,8–11] Such evidence supports the idea that SR is fueled by a general resource that can be consumed on any task that requires conscious behavioral, emotional, or cognitive modifications.[6] SRD also has been distinguished experimentally from the effects of sleep deprivation and fatigue.[12] Thus, SRD can be considered a unique cognitive resource independent of other factors that affect performance.

There are specific interventions that decrease the SRD effect, or in essence, improve performance on subsequent tasks requiring high SR. Brief periods of rest or relaxation,[13,14] priming acts of SR (ie, when a stimulus in the surrounding environment influences performance on a self-regulatory task),[15] affirming core values,[16] and the induction of positive affect (eg, via receiving a small unexpected gift or watching an amusing video clip)[17,18] have led to a reversal of SRD in many studies. This reversal is referred to as self-regulatory repletion (SRR).

Although studies of SR have spanned multiple behaviors from self-presentation[19] to coordinating communication,[20] to date, research has not addressed the role of SR in vocal behavior, voice disorders, or voice treatment. This is a critical gap in the literature because the need to regulate phonation may ultimately impinge on the generalization of new vocal

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behaviors.[21] SR may negatively affect patient adherence to practice schedules as well as vocal health recommendations (eg, drinking water, refraining from smoking). Similarly, regulating behaviors in daily life (eg, refraining from eating a desired food or suppressing emotions) may actually have a deleterious effect on a patient's ability to modify his or her vocal behavior inside and outside of voice therapy. Figure 1 is a proposed model of SRD effects on voice therapy outcomes.

Because there is no experimental design for examining self-regulatory processes related to vocal behavior or voice therapy, the current investigation used Lombard effect suppression (LES). The Lombard effect is the well-studied phenomenon in which individuals increase their vocal intensity in the presence of noise.[22–26] Background noise increases the difficulty of engaging in efficient communication and auditory self-monitoring and consequently results in greater vocal effort.[27–30] The Lombard effect is activated without conscious effort or awareness.[27,29–31] Maladaptive functional vocal behaviors such as speaking with increased muscle tension and poor respiratory support are analogous to the Lombard effect as they are typically produced automatically and with little attention. Thus, asking persons to explicitly inhibit increases in their vocal intensity may serve as a model for the modification of functionally maladaptive vocal behavior in voice therapy. Explicitly inhibiting the Lombard effect (ie, LES) and changing vocal technique require individuals to consciously override and replace habituated vocal behaviors.[32] Thus, in both cases, a relatively automatic behavior must be voluntarily controlled.

The purpose of the present study was to better understand the role of SR phenomena in vocal modification. Specifically, we wanted to determine whether SRD affects the voluntary alteration of automatic vocal behavior (LES) in reading and in free speech. If SRD does affect voluntary changes in automatic vocal behavior, we wondered whether a relaxation intervention (ie, SRR) could reverse the negative effects of SRD on vocal manipulations. On the basis of prior studies of SRD and SRR,

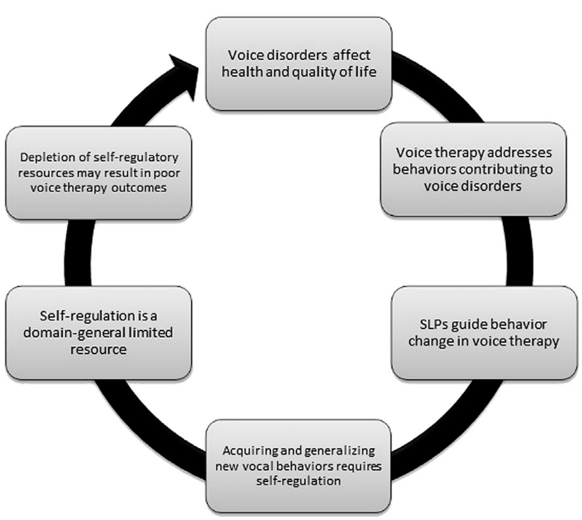

FIGURE 1. Proposed model of self-regulatory depletion effects on voice therapy outcomes.

we hypothesized that participants would exhibit (1) reduced LES when reading aloud after a high-SR task versus a low-SR task; (2) reduced LES when producing free speech after a high-SR task versus a low-SR task; and (3) improved LES when reading or producing free speech after a high-SR task followed by a guided relaxation task, versus a high-SR task followed by no relaxation task.

METHODS

Participants

One hundred four female undergraduate students aged 18–23 years were recruited from the University of Wisconsin-Madison's Communication Sciences and Disorders subject pool. We recruited only female undergraduate students to minimize variability in the sample, given that SR may differ between women and men.[33] Participants were excluded from this research if they reported a diagnosed neurological or psychological condition that affected thinking, scored above 35% on the overall severity visual analog scale of the Consensus-Auditory Perceptual Evaluation of Voice (CAPE-V)[34,35] as rated by the first author (L.A.V.), or reported a current voice disorder or diagnosis of a voice disorder within the last 2 years. Participants were included in this research if they were fluent in English as indicated by self-report, passed a hearing screening, and scored below 10 on a depression screening questionnaire, the Patient Health Questionnaire-9 (PHQ-9).[36] Screening of depression took place because depressed mood may negatively affect SR.[17,18] One participant was excluded for scoring above threshold on this measure. Thus, the total number of participants included in analysis was 103.

Experimental protocol

This study used a between-subjects design. Participants were randomized into one of three groups by a predetermined randomization schedule. See Table 1 for task completion by group. The first group was a low self-regulation (LSR) group that engaged in a low self-regulatory writing task followed by high self-regulatory vocal tasks. The second group was a high self-regulation (HSR) group that engaged in a high self-regulatory writing task followed by the same high self-regulatory vocal tasks as the LSR group. The third group was a high self-regulation intervention (HSRint) group that engaged in the same high self-regulatory writing task as the HSR group and the same high self-regulatory vocal tasks as both other groups but received a relaxation intervention between the writing and vocal tasks. Both HSR and LSR groups did not receive a break between the writing and vocal tasks. In addition to the main experimental tasks, manipulation checks were conducted to ensure that experimental manipulations had their intended effects on participants.[7,13,15–17,20]

Tasks

Explanations of task procedures, in the order in which they were completed, are described in Table 2 and further detailed in the following:

TABLE 1.
Tasks Completed by Each Group

Group	Questionnaires	Writing Tasks	Manipulation Check 1	Relaxation Task	Manipulation Check 2	High-Regulation Vocal Tasks with Manipulation Checks
HSR	X	X (High)	X			X
HSRint	X	X (High)	X	X	X	X
LSR	X	X (Low)	X			X

Note: The low and high variant of the writing task is specified per group.
Abbreviations: X, completed task listed in column header; HSR, high self-regulation; HSRint, high self-regulation intervention; LSR, low self-regulation.

1. Questionnaires/Testing (all groups): Participants filled out several questionnaire measures before engaging in main experimental tasks. A demographics questionnaire asked participants to indicate information such as age, GPA, and experience with a list of SR-demanding activities (participation in acting, singing, sports, instrumental, and dancing activities within the last 10 years). Participants also filled out the PHQ-9[36] and a fatigue questionnaire to indicate perceived levels of depressive symptoms and fatigue, respectively. Participants were administered the Color Word Interference Test (CWIT) inhibition condition from the Delis-Kaplan Executive Function System (D-KEFS)[37] and completed the Behavioral Inhibition Behavioral Activation Scales (BIS/BAS),[38] and Behavior Rating Inventory of Executive Function-Adult (BRIEF-A).[39] The CWIT and BRIEF-A are measures of executive function, and the BIS/BAS assesses features of behavioral motivation. The previously mentioned measures acted as randomization checks. That is, they were completed to ensure that demographics, fatigue, depressive symptoms, executive function, and motivational characteristics were randomly distributed across groups.
2. Writing tasks (all groups): These tasks involved participants writing a story about a recent vacation using paper and pen for 6 minutes and varied in difficulty depending on group membership. Participants in the LSR group wrote their story for the 6-minute time block without any restrictions. Participants in the HSR and HSRint groups were directed to write their story without using the letters “a” or “n.” In other words, participants were instructed to avoid using words that had these letters within them. This task and the LSR group’s writing task were replicated from previous studies of the SRD effect.[40]
3. Manipulation check 1 (all groups): During the first manipulation check, each participant rated the degree of mental effort exerted to complete her assigned writing tasks from 0 (no mental effort exerted) to 10 (very, very strong mental effort exerted) on a modified version of the Borg CR-10 scale.[41] Ratings of mental effort were used to ensure that the high SR writing task was perceived as more mentally taxing by the HSR/HSRint than the low SR writing task was perceived by the LSR groups. Participants also rated their current mood on the Brief Mood Introspection Scale (BMIS).[42] The

TABLE 2.
Means and Standard Deviations of Ratings on Manipulation Check Measures by Group

Group	HSR, n = 34	HSRint, n = 34	LSR, n = 35
Borg CR-10 Mental Effort Scale			
Writing task†	6.76 (1.85)	6.94 (1.87)	2.87* (1.91)
Baseline reading task	4.56 (2.09)	4.03 (1.71)	4.27 (2.06)
High-regulation reading task	4.89 (1.98)	4.78 (1.95)	4.37 (1.73)
Baseline speaking task	6.27 (2.18)	5.59 (2.14)	5.17 (2.12)
High-regulation speaking task	5.80 (2.46)	5.38 (2.31)	5.37 (2.29)
Borg CR-10 Vocal Effort Scale			
Vocal effort rating for baseline reading task	3.89 (2.00)	3.41 (1.60)	3.16 (1.81)
Vocal effort rating for high-regulation reading task	3.33 (1.63)	3.36 (1.44)	3.17 (1.97)
Vocal effort rating for baseline speaking task	4.20 (1.94)	3.75 (2.05)	3.36 (2.05)
Vocal effort rating for high-regulation speaking task	4.39 (2.12)	4.22 (2.24)	3.73 (2.35)

Abbreviations: HSR, high self-regulation; HSRint, high self-regulation intervention; LSR, low self-regulation.
* Group is significantly different from others ($P < 0.05$).
† Sample size for HSR and HSRint was 33 due to missing participant data.

BMIS asks participants to rate how lively, happy, sad, tired, caring, content, gloomy, jittery, drowsy, grouchy, peppy, nervous, calm, loving, fed up, and active they feel on a four-point scale ranging from "definitely do not feel" to "definitely feel." These ratings of mood were calculated into index scores representing pleasant-unpleasant mood and arousal-calm mood. Higher scores on each of these indexes represent greater pleasant mood and arousal, respectively. Pleasant-unpleasant and arousal-calm index scores were used to ensure that there were no significant between-group differences in mood effects after the low- and high-SR writing tasks, given that positive and negative mood can improve or worsen SR, respectively.[13,15–17]

4. Relaxation task (HSRint): Participants in the HSRint group were provided with a relaxation intervention directly after they completed the high SR writing task. During this period, they were invited to sit in a comfortable chair in a quiet, darkened room, and listen to a prerecorded relaxation narrative via an iPod nano (Apple Corporation, Cupertino, CA) and headphones (Royal Philips Electronics, Amsterdam, Netherlands). The narrative guided participants to relax their muscles through visual imagery and specific directions set to music. Before the recording began, participants were directed to relax as much as possible, listen to the narrative, and follow its instructions until stopped by the experimenter (after 6 minutes).
5. Manipulation check 2: Similar to the writing tasks, participants rated the degree that the relaxation task was mentally effortful on a modified version of the Borg CR-10 and also rated their current mood on the BMIS. Mental effort ratings were collected to ensure that the HSRint group perceived the relaxation task as less mentally taxing than the high SR writing task. The BMIS was used to determine whether the SRR manipulation increased positive mood because positive effect may replete self-regulatory resources.[17]
6. Vocal tasks and additional manipulation checks (all groups): Individuals in the HSR and LSR groups completed vocal tasks and associated manipulation checks directly after manipulation check 1, whereas the HSRint group completed these tasks after manipulation check 2. Two reading and two speaking tasks were completed by each group. The first reading and speaking tasks were used as baseline measures for determining LES. That is, these tasks involved elicitation of the Lombard effect without asking participants to suppress it. The second reading and speaking tasks required participants to suppress the Lombard effect and were meant to require high self-regulatory effort. All vocal tasks were audio-recorded.
   a. Reading tasks
      i. Baseline reading (all groups): Participants were instructed to read a series of phonetically balanced passages[43–46] until they were stopped by the experimenter. Each participant read for exactly 4 minutes, and after the first 2 minutes, 70 dB HL of cafeteria noise was delivered to her headphones binaurally to elicit the Lombard effect. In other words, the first 2 minutes involved the participant reading in quiet and the last 2 minutes involved the participant reading in noise. After this task, participants completed manipulation checks. Specifically, they indicated their current mood on the BMIS and two modified versions of the Borg CR-10. One version asked participants to indicate how mentally effortful the reading task was from 0 (no mental effort) to 10 (very, very strong mental effort), and the other asked participants to rate the degree of vocal effort they felt they exerted when reading from 0 (no vocal effort) to 10 (very, very strong vocal effort). Vocal effort was operationally defined as the amount of physical effort it takes to produce or make a voice. The Borg CR-10 scale has been adapted in previous studies to quantify ratings of perceived vocal effort.[47]
      ii. High-regulation reading (all groups): Following baseline reading, participants were instructed to continue reading phonetically balanced passages until stopped by the experimenter (after 4 minutes). Methods for the timing and delivery of cafeteria noise were the same as those described for baseline reading. Unlike the baseline reading task, participants were instructed to maintain their vocal intensity between the quiet and noisy conditions (ie, engage in LES). Following this task, participants completed manipulation checks in which they rated the mental effort and vocal effort exerted during high-regulation reading on the modified versions of the Borg CR-10 and their current mood on the BMIS.
   b. Free speech tasks
      i. Baseline free speech (all groups): After performing both reading tasks, participants were instructed to choose a topic to discuss. Their choices included movies, music, food, or school. Methods for the timing and delivery of cafeteria noise were the same as those described for the previous vocal tasks, but instead of reading in quiet and then noise, participants spoke extemporaneously in 2 minutes of quiet followed by 2 minutes of noise. After this task, participants completed the mental effort, vocal effort, and mood manipulation check ratings previously described for the reading tasks.
      ii. High-regulation free speech (all groups): After completing baseline free speech, participants were instructed to pick another topic from the remaining three to discuss until stopped by the experimenter. The participant's voice was recorded as they spoke. Methods for the timing and delivery of cafeteria noise were the same as those described for all

previous vocal tasks; however, participants were instructed to maintain their vocal intensity between quiet and noisy conditions (ie, engage in LES). After this task, participants completed the mental effort, vocal effort, and mood manipulation check ratings previously described for the baseline speech task.

The modified Borg mental effort ratings were taken after each vocal task to determine whether high-regulation free speech and reading tasks were perceived as more mentally taxing than each baseline free speech and reading task, respectively. These ratings were also compared across groups to ensure that there were no between-group differences in perceived mental exertion. Finally, ratings were examined to determine whether perceptions of reading versus speaking were significantly different across participants.

The modified Borg vocal effort ratings were used to compare how participants perceived physical vocal effort on different vocal tasks (ie, baseline reading vs high-regulation reading) and ensure that vocal effort ratings were not significantly different between groups on the same vocal task. It was expected that vocal effort would be perceived as greater on baseline tasks when participants were not directed to suppress the Lombard effect, as opposed to during high-regulation tasks when participants' voices were likely softer. The BMIS pleasant-unpleasant and arousal-calm subscales[42] were used to ensure that there were no significant between-group differences in mood effects after each speaking and reading task.

Instrumentation

For a schematic of experimental configuration for the vocal tasks, see Figure 2. Instrumental setup and selected equipment are partially based on specifications suggested by Spielman et al.[48] Participants completed vocal tasks in a single-walled soundproof booth (Controlled Acoustical Environment; Industrial Acoustics Company, Inc. Bronx, NY) and listened to cafeteria noise, fed through headphones (Telephonic Corporation, Farmingdale, NY), while speaking into a Countryman Isomax B3 omnidirectional condenser microphone with a flat frequency response (Countryman Associates Corporation, Menlo Park, CA). The microphone was mounted on a Sennheiser NB2 head mount (Sennheiser Electronics Corporation, Old Lyme, CT) and attached directly to the body of the headphones, positioned at a 10-cm mouth-to-microphone distance, and inserted into a dual channel USBPre microphone interface for computer audio (Sound Devices, LLC, Reedsburg, WI). The USBPre interface, acting as an analog-to-digital converter, was then connected directly to an Apple Imac (4,1) desktop computer (Apple Corporation, Cupertino, CA) equipped with the acoustic analysis program *Praat* Version 5.3.04 (Boersma & Weenink, 2011).[49] Wav files of the participants' phonation in reading and speech, in both noisy and quiet conditions, were saved to the computer through *Praat*.

To deliver standard cafeteria noise (calibrated at 70 dB HL) to each participant's ears, headphones were connected to a digital audiometer (Grason Stadler Corporation, Eden Prairie, MN). The audiometer was connected to a CD player (Pioneer Electronics Corporation, Kawasaki, Kanagawa, Japan) that was used to play cafeteria noise[50] at 70 dB HL.

Acoustic analysis

Acoustic analysis of each vocal task was completed. The following operations were automated by a *Praat* script which

(1) segmented recordings of the acoustic voice signal during each of the four vocal tasks into 80 seconds in the quiet period and 80 seconds of the vocal acoustic signal in the noisy period. The first and last 20 seconds of phonation in each quiet and noisy period were omitted to control for vocal onset and offset and any extended pausing due to the initial delivery of cafeteria noise.

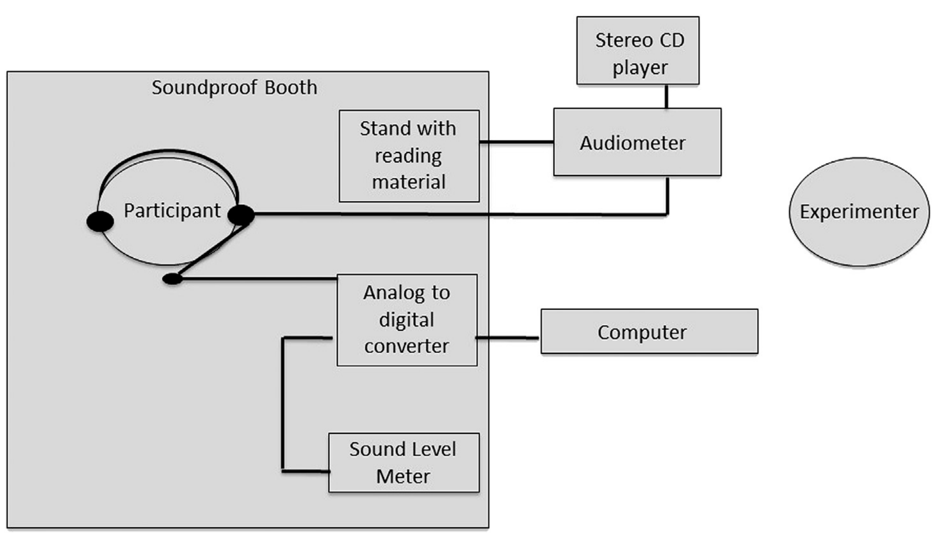

FIGURE 2. Schematic of reading and free speech task setup.

(2) removed both pauses and unvoiced sounds longer than 0.1 second and at or below −25 dB for both 80-second acoustic segments of each vocal task.
(3) calculated mean intensity in dB SPL for the first 80-second segment (quiet conditions) and second 80-second segment (noisy conditions) for each of the four vocal tasks.
(4) imported the two mean intensities for each of the four vocal tasks into an excel file.

After the acoustic files were processed via the *Praat* script, difference scores were calculated by subtracting the mean intensity of the vocal signal calculated for the first 80 seconds (quiet conditions) of each task from the mean intensity of the vocal signal calculated for the second 80 seconds (noise conditions) of each task. This calculation represented the extent of the Lombard effect for each task (baseline reading, high-regulation reading, baseline speaking, and high-regulation speaking). To then generate the main dependent variable values (extent of LES in reading and speaking), changes in the amount of the Lombard effect from both baseline reading to high-regulation reading, and baseline free speech to high-regulation free speech, were calculated. Specifically, an LES value was calculated for reading by subtracting the extent of the Lombard effect (change in mean vocal intensity from quiet to noisy conditions) during the baseline condition from the extent of the Lombard effect during the high-regulation condition. An LES value for free speech was calculated in the same manner as was described for reading. Figure 3 is a graphic representation of this calculation.

Statistical analyses

Manipulation checks. A one-way ANOVA was used to determine whether the initial writing task was perceived as significantly less effortful by the LSR group versus the HSR and HSRint groups. An ANOVA was also used to determine whether there were any significant differences detected among groups on mood ratings (BMIS) after the completion of the regulated versus free writing tasks and after completion of each vocal task. Paired sample *t* tests were used to compare the HSRint group's ratings of mental effort and mood after the writing task, to mental effort and mood ratings after the relaxation task. These analyses were performed to determine if the relaxation intervention positively affected mood to facilitate SRR. Paired sample *t* tests were also performed to determine whether participants perceived vocal and mental effort as greater on the high-regulation reading versus the baseline reading tasks, high-regulation speaking versus baseline speaking tasks, baseline speaking versus baseline reading tasks, and high-regulation speaking versus high-regulation reading tasks. Finally, ANOVA was used to determine whether significant differences in perceived mental and vocal effort existed among groups after each vocal task. For each ANOVA, pairwise comparisons were made between groups using Fisher's protected least significant difference (LSD) test.

Randomization checks. An ANOVA was performed to examine whether there were significant differences among groups on demographic variables, the D-KEFS CWIT, BIS/BAS, PHQ-9, fatigue, and BRIEF-A scores. A chi-square analysis was used to examine if there were any differences between the number of individuals in each group who participated in singing, acting, sports, instrumental, and dancing activities within the previous 10 years.

Tests of study questions. Analysis of covariance (ANCOVA) was performed to examine group differences in LES for reading and free speech using the extent of the Lombard effect in the baseline reading and baseline free speech tasks as a covariate, respectively. Baseline tasks were used as covariates because the size of LES in reading and speech may have been influenced by the extent of the Lombard effect at baseline. Pairwise comparisons were made between groups using Fisher's protected LSD test.

RESULTS

Manipulation checks

Before reviewing the results of the main hypotheses, the outcome of the manipulation and randomization checks will be discussed. Overall, these checks indicated that the manipulations used in this study were effective and that groups did not differ on baseline measures.

Manipulation checks compared across groups. Mental effort and vocal effort manipulation checks for writing and vocal tasks results for all groups are summarized in Table 2. The Modified Borg CR-10 ratings were significantly different among groups, $F(2, 98) = 52.07$, $P < 0.001$. Post hoc

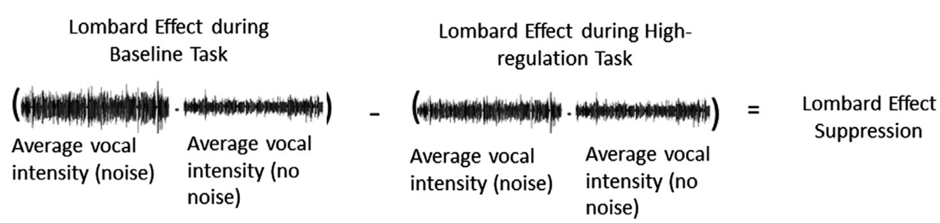

FIGURE 3. Visual representation of how LES in speaking and reading were derived. Specifically, the average intensity of the Lombard effect was determined for each baseline and high-regulation task by subtracting average vocal intensity of the vocal acoustic signal during quiet conditions from the average vocal intensity of the vocal acoustic signal during noisy conditions. Then, the difference score calculated for the baseline reading task was subtracted from the difference score calculated for the high-regulation reading task to derive Lombard effect suppression in reading. The difference score calculated for the baseline free speech task was subtracted from the difference score calculated for the high-regulation speech task to derive Lombard effect suppression in free speech.

comparisons using Fisher's LSD revealed that the HSR group ($P < 0.001$) and HSRint group ($P < 0.001$) rated the high-regulation writing task as significantly more effortful than the LSR group rated the low-regulation writing task. The HSR versus HSRint ratings of perceived mental effort did not differ significantly ($P = 0.65$).

There were no significant differences among groups in perceived mental effort, as measured via the Modified Borg CR-10 scale, on the baseline reading task, $F(2, 100) = 0.82$, $P = 0.45$; high-regulation reading task, $F(2,100) = 0.62$, $P = 0.54$; baseline speaking task, $F(2,100) = 2.02$, $P = 0.14$; or high-regulation speaking task, $F(2,100) = 0.3$, $P = 0.74$. Similarly, perceived vocal effort was not significantly different among groups on any reading or speaking task: Baseline reading, $F(2, 100) = 2.08$, $P = 0.13$; high-regulation reading, $F(2,100) = 0.13$, $P = 0.88$; baseline speaking, $F(2,100) = 1.53$, $P = 0.22$; and high-regulation speaking, $F(2,100) = 0.84$, $P = 0.44$.

There were no significant differences among groups in self-reported mood after the initial writing task, as measured by the BMIS pleasant-unpleasant scale, $F(2,100) = 1.14$, $P = 0.32$, and arousal-calm scale, $F(2, 100) = 2.6$, $P = 0.08$. Similarly, there were no significant differences among groups in perceived mood after the reading and free speech tasks, on the pleasant-unpleasant scale, $F(2,100) = 0.16$, $P = 0.85$, or the arousal-calm scale, $F(2,100) = 1.67$, $P = 0.19$. In both cases, results indicated that any significant differences on the writing or vocal tasks were not likely related to mood effects.

Effect of intervention within the high self-regulation intervention group. See Table 3 for descriptive statistics of mood and mental effort ratings in the HSRint group before and after the intervention task. A paired sample *t* test revealed a significant positive change in mood in the HSRint group after participation in the high-regulation rating task to after participation in the relaxation intervention, as measured by BMIS pleasant-unpleasant rating scale, $t(32) = 2.93$, $P = 0.01$; and arousal-calm rating scale, $t(33) = -6.18$, $P < 0.001$. These results indicate that participants reportedly felt significantly calmer and more pleasant after the relaxation task. Furthermore, participants in the HSRint group rated the high-regulation writing task as significantly more cognitively effortful than the intervention task, $t(32) = -13.16$, $P < 0.001$.

Perceived mental and vocal effort on free speech versus reading tasks (all participants). Table 4 summarizes descriptive statistics for average ratings of mental effort and vocal effort across all participants for reading versus free speech tasks. Paired sample *t* tests revealed that the perceived mental effort required for the baseline reading and baseline free speech tasks were not significantly different than their high-regulation counterparts for reading, $t(102) = -1.86$, $P = 0.07$ and for speaking, respectively, $t(102) = 0.84$, $P = 0.41$. On the other hand, baseline reading and high-regulation reading were rated as significantly less mentally effortful than the baseline free speech, $t(102) = -6.22$, $P < 0.001$ and high-regulation free speech tasks, respectively, $t(102) = -5.13$, $P < 0.001$. Paired sample *t* tests also revealed that ratings of vocal effort were not significantly different between baseline reading and high-regulation reading tasks, $t(102) = 1.42$, $P = 0.16$; and between baseline free speech and high-regulation free speech tasks, $t(102) = -1.35$, $P = 0.18$. Ratings of vocal effort were significantly lower for high-regulation reading versus high-regulation free speech, $t(102) = -6.22$, $P < 0.001$; and for baseline free speech versus high-regulation free speech, $t(102) = -2.91$, $P = 0.004$. These results indicate that participants perceived reading to be less effortful both vocally and mentally.

Correlation of vocal and mental effort for reading and speaking tasks. Although vocal effort and mental effort ratings were defined as distinct constructs, and time was devoted to specifically defining vocal effort, there were moderate and significant positive correlations between vocal and mental effort ratings for baseline reading, $r(101) = 0.62$, $P < 0.001$;

TABLE 3.
Means and Standard Deviations for Mood (BMIS [Brief Mood Introspect scale]) and Mental Effort (Borg CR-10 [Borg Category Ratio 10]) Ratings by the HSRint (High Self-Regulation Intervention) Group Before and After Relaxation

Group	HSRint Group (n = 34)
Borg CR-10 Mental Effort Scale	
Postwriting*	6.76† (1.89)
Postrelaxation task*	1.36 (1.68)
BMIS pleasant-unpleasant mood scale score	
Postwriting	44.41† (5.96)
Postrelaxation intervention	46.38 (5.15)
BMIS arousal-calm mood scale score	
Postwriting	25.74† (3.31)
Postrelaxation intervention	22.53 (3.26)

Note: Postwriting, after writing task; Postrelaxation, after the relaxation task.
* Sample size was n = 33 for this data.
† Significant differences exist between this and subsequent variable ($P < 0.05$).

TABLE 4.
Means and Standard Deviations for Vocal and Mental Effort (Borg CR-10 [Borg Category Ratio 10]) Ratings by Baseline Reading and Writing and High-Regulation Reading and Writing Tasks for All Groups (n = 103)

Group	Baseline	High Regulation
Borg CR-10 Mental Effort Rating		
Reading task	4.31* (1.95)	4.64* (1.87)
Free speech task	5.67 (2.16)	5.53 (2.32)
Borg CR-10 Vocal Effort Rating		
Reading task	3.53 (1.88)	3.29* (1.67)
Free speech task	3.77† (1.99)	4.11 (2.21)

* Significant differences exist between this row and subsequent row ($P < 0.05$).
† Significant differences exist between this column and adjacent column ($P < 0.05$).

TABLE 5.
Means, Standard Deviations, and ANOVA Results for All Randomization Check Variables

Group	HSR (n = 34)	HSRint (n = 34)	LSR (n = 35)	*F*	*df*	Sig. (Two Tailed)
Age	18.91 (1.08)	18.91 (0.87)	19.23 (1.03)	1.16	2100	0.32
GPA	3.43 (0.57)	3.44 (0.41)	3.54 (0.42)	0.57	2100	0.57
CAPE-V overall severity	7.03% (8.78)	7.15% (8.22)	6.46% (6.54)	0.08	2100	0.93
BRIEF-A Behavioral Regulation Inventory	45.47 (6.09)	46.68 (8.03)	45.66 (9.71)	—	—	0.63 (via Kruskal-Wallis test)
Fatigue Rating	4.53 (1.76)	4.71 (1.99)	4.66 (1.85)	0.08	2100	0.92
Patient Health Questionnaire-9	2.79 (2.36)	3.00 (2.10)	2.94 (2.27)	0.08	2100	0.93
D-KEFS Inhibit Condition Scale Score	12.41 (1.26)	12.03 (1.90)	12.37 (1.91)	0.51	2100	0.60

Abbreviations: HSR, high self-regulation; HSRint, high self-regulation intervention; LSR, low self-regulation; GPA, grade point average; CAPE-V, Consensus Auditory-Perceptual Evaluation of Voice; BRIEF-A, Behavioral Rating Inventory of Executive Function-Adult; D-KEFS, Delis Kaplan Executive Function System.

high-regulation reading $r(101) = 0.55$, $P < 0.001$; baseline free speech $r(101) = 0.67$, $P < 0.001$; and high-regulation free speech, $r(101) = 0.82$, $P < 0.001$.

Randomization checks

Table 5 lists summary data for all baseline study measures. There were no significant between-groups differences on any measure. Scores were compared using ANOVA for all measures except the BRIEF-A. Because of homogeneity of variance violations detected via Levene's test, $F(2, 100) = 4.7$, $P = 0.01$, a nonparametric independent-samples Kruskal-Wallis test was used to compare groups on the BRIEF-A. Results revealed no significant differences among groups.

As summarized in Table 6, there were no significant between-groups differences in number of participants who reported engaging in singing, acting, dancing, sports, or instrumental activities within the previous 10 years.

Main outcome: Lombard effect suppression

Missing or excluded data. One participant from the HSRint group was an extreme outlier (3 standard deviations above the median) and excluded from analysis for LES in both reading and speaking. LES in reading could not be calculated for two participants in the HSRint group and two participants in the LSR group because of missing or incorrectly timed acoustic files. Thus, the number of participants examined for LES in reading was 34 for the HSR group, 31 for the HSRint group, and 33 for the LSR group. For LES in speaking, acoustic data for one participant in the HSR group were missing. Thus, the number of participants for LES in speaking was 33 for the HSR group, 33 for the HSRint group, and 35 for the LSR group.

Group differences in Lombard effect suppression. Table 7 summarizes summary data for LES effects in the three groups. There was a significant main effect of group on LES in

TABLE 6.
Descriptive Statistics and Chi-Square Results for Participant Activities, Within the Last 10 Years, by Group

Group	χ^2	*df*	Sig. (Two Tailed)	HSR Group	HSRint Group	LSR Group	Total
Voice activities	0.98	2	0.61				
Yes				21	17	19	57
No				13	17	16	46
Acting activities	4.01	2	0.14				
Yes				17	9	13	39
No				17	25	22	64
Sports activities	1.10	2	0.59				
Yes				33	33	35	101
No				1	1	0	2
Instrumental activities	3.17	2	0.21				
Yes				25	18	21	64
No				9	16	14	39
Dancing activities	0.99	2	0.61				
Yes				16	12	15	43
No				18	22	20	60

Abbreviations: HSR, high self-regulation; HSRint, high self-regulation intervention; LSR, low self-regulation.

TABLE 7.
Average LES (dB SPL) Per Group and Standard Errors

Group	HSR Group	HSRint Group	LSR Group
Reading	3.26 (0.28) n = 34	3.16 (0.29) n = 31	3.15 (0.28) n = 33
Free Speech	0.62 (0.29) n = 33	0.89 (0.30) n = 33	1.72* (0.30) n = 35

Note: This value was adjusted for the change in acoustic vocal signal from quiet to noisy conditions in baseline reading and baseline speaking tasks.
Abbreviations: HSR, high self-regulation; HSRint, high self-regulation intervention; LSR, low self-regulation.
* Group is significantly different from others ($P < 0.05$).

speaking, $F(2,98) = 3.79$, $P = 0.03$. As predicted, pairwise comparisons via Fisher's LSD test indicated that the HSR group showed significantly less suppression (ie, more depletion) than the LSR group ($P = 0.01$; ES = 0.56), but that there was no significant difference between the HSR and HSRint groups ($P = 0.52$; ES = 0.09). The HSRint group showed significantly less suppression (more depletion) than the LSR group ($P = 0.05$; ES = 0.45). There was no significant effect of group on LES in reading, $F(2,95) = 0.05$, $P = 0.95$.

DISCUSSION

The purpose of this study was to determine whether SR-related phenomena described in the psychological literature also applied to vocal behaviors. We constructed an experimental model of SR using a well-studied vocal control task, Lombard effect suppression, to test hypotheses related to effects of SR depletion and repletion on subsequent vocal behaviors. In the following sections, we discuss main study outcomes and findings on specific measures and consider next steps to translate literature on SR to clinical intervention for voice patients.

It was hypothesized that participants would exhibit less suppression of the Lombard effect on vocal tasks if those tasks followed an SR-demanding task (regulated writing). This hypothesis was partially supported. Specifically, participants who had engaged in an SR-demanding task showed less LES suppression on a subsequent free speech task. These results suggest that SR depletion can affect vocal performance as it does other behavioral and psychological phenomena, consistent with previous empirical studies and theoretical accounts of SR as a single set of resources that is shared across psychological functions.[7–10,40]

We hypothesized that SRD would affect reading aloud as well as free speech, but this hypothesis was not supported. The lack of an effect on reading performance was not because resources were not depleted on the reading task, as participants' ratings of depletion were the same before reading as before speaking. The most likely explanation is that reading is not as cognitively taxing as extemporaneous speaking,[51] so participants had more SR resources available for the high-regulation reading task. The Lombard effect is generally greater and more difficult to suppress in speaking than in reading,[23–25,29,52] which further supports the notion that speaking is more cognitively demanding. Consistent with this interpretation, participants rated both baseline and high-regulation reading as significantly less mentally effortful than corresponding free speech tasks. In contrast to the reading task, when performing the free speech task, participants were subject to dual task loading because they were attempting to formulate and communicate their message while suppressing the Lombard effect. In this case, SR depletion likely is related to a trade-off between cognitive resources needed for maintaining vocal intensity and those required for formulating a message.

The third hypothesis was that SR resources would be repleted by a relaxation intervention, with resulting benefits to LES. This hypothesis also was not supported, as there was no significant effect of the relaxation intervention on LES in this study. The lack of an effect may be because the intervention was not effective; however, participants reported increased relaxation and pleasant mood after the intervention, both of which have been associated with repletion in prior studies.[16,53] Similarly, the intervention group reported significantly less mental effort on the relaxation task than the writing task.

Potential limitations

It was expected that baseline reading and free speech would be rated as significantly less mentally effortful than high-regulation reading and speaking—that is, that participants would rate themselves as exerting more mental effort when they were suppressing the Lombard effect than when voicing naturally—but there was no significant difference in baseline versus high-regulation task ratings. As LES effects were observed nonetheless, the flaw appeared to be with the rating scale rather than the experimental manipulation. Perhaps, participants were thinking less about voice and more about the content of the tasks (eg, reading text vs generating text), which is consistent with the high correlation between mental and vocal effort ratings on all conditions. Future work should ensure that directions for ratings of mental effort on tasks with a dual-task component specify what, in particular should be evaluated, so that it is easier to interpret and compare perceived effort between tasks. The implications of this finding may be that individuals, in general, have a difficult time distinguishing self-perceived physical vocal effort from cognitive exertion.

Another potential limitation of the study was that SR depletion effects may have been counteracted, in part, by the physical layout of the experiments. Because of space constraints, participants performed the writing task in one room and the relaxation and vocal tasks in another. It took a few minutes to guide each participant back and forth between spaces as well as through calibration procedures and setup in the soundproof booth. Thus, while brief, the time between SR-depletion and -repletion tasks and vocal tasks could have affected results. The most likely direction of this effect would be to mitigate SR depletion effects, as rest may be a source of SR repletion.[13]

We also acknowledge that different levels of experience with self-regulatory activities both specific to vocal skill (voice lessons; choir) and more generally (dancing, acting, sports, and instrumental activities) may interact with the capacity to exert vocal control. Although there were no significant between-groups differences in number of participants who reported engaging in these activities within the previous 10 years, future research should specifically examine how differing levels of vocal, acting, theater, sports, and dancing training interact with self-regulatory depletion and vocal task performance.

Finally, participants were a relatively homogeneous sample of young women who performed a simple loudness-monitoring task. There is much to be learned about how these findings translate to clinical population and to other facets of phonation such as pitch and quality.

Clinical implications

This study suggests that self-regulatory phenomena do apply to the modification of vocal behavior in extemporaneous speaking situations. Referring back to the proposed model in Figure 1, study results confirm the part of the model that indicates that the acquisition and generalization of new vocal behaviors require SR and may pertain to vocal modifications made in voice therapy as well. Specifically, SRD may negatively influence vocal modification which may, in turn, result in poor voice therapy outcomes (Figure 1). Everyday engagement in self-regulatory tasks, especially for voice patients attempting to make changes related to vocal health (smoking cessation, increasing hydration) may negatively affect vocal behavior change in spontaneous speaking. Similarly, concluding that a patient has achieved a vocal target via assessing reading only may be erroneous because self-regulatory demands across readings and speaking do not appear to be equal.

Finally, this study did not find that guided relaxation repleted self-regulatory resources. Muscle relaxation practices are typically used in voice therapy to help patients release “excess tension” and improve awareness of bodily states.[1,4,54] The present results, if replicated in a clinical context, suggest that relaxation might indeed improve mood, but whether such practices replete cognitive resources is still in question. Tuning into one’s own bodily states and willfully attempting to relax may actually use rather than replete cognitive resources. Thus, if repleting mental resources is an objective for clinician and patient during aspects of the voice therapy process, relaxation as elicited here may not be the most effective SRR strategy.

Although many studies support the effectiveness of voice therapy in remediating voice disorders,[3,55–57] our findings show the importance of a broader understanding of factors that may help or hinder successful learning and modification of vocal technique and related behaviors, especially given the growing emphasis on efficiency and evidence-based treatment in the United States health care system.[58] In short, although voice therapy is clearly effective, the way in which the clinician directs patients, formulates recommendations, and structures therapy sessions requires consideration of SR to better facilitate vocal behavior change and maximize permanent gains. The present research includes theory, methods, and a model that can be further modified and refined, as well as applied toward studying the unexamined intricacies that likely affect vocal behavior change and the therapeutic process.

CONCLUSIONS

This study provided preliminary evidence for the role of SR in vocal modification. Results support the idea that cognitive effort on preceding tasks may be a factor in the ability to make voice modifications, particularly in extemporaneous speech. Although results and methods are preliminary, it is hoped that this approach to investigating SR and vocal behavior can be further developed, refined, and eventually used within clinical voice contexts.

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