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Energy in the Air and Psychological Work: Examining the Relationship Between Oxygen and Self-Regulation

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Evidence indicates that self-regulation relies on glucose as a limited energy source, such that self-regulation is impaired when glucose is lower and is improved when glucose is higher. Two studies examined whether levels of oxygen, the other primary energy for the brain, also influences self-regulation. While completing the Stroop task, participants breathed through a paper bag that either did or did not reduce oxygen levels (Study 1) or, while completing a measure of prejudice, participants breathed through a paper bag that either did or did not reduce oxygen levels and that either did or did not have increased oxygen flowing through it (Study 2). Results indicated that these manipulations of oxygen levels did not influence Stroop performance or prejudice. Minor fluctuations in oxygen levels thus do not appear to influence self-regulation.

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The human psyche can be viewed as a system of energy, in that its existence relies upon the continual use of energy by biological cells in the brain. These cells take in primarily glucose and oxygen, and they transform these energies into work that allows the psyche to control its internal and external environment. To work is to use energy, and thus the psyche should, in theory, be less capable of working upon the internal and external environment when its energy is lower (vs. higher). The proposed studies will examine the link between one form of energy (i.e., oxygen) and one form of work (i.e., self-regulation). Self-regulation is the process by which the psyche performs work upon itself or the external environment, such as by controlling thoughts, emotions, and urges, as well as overriding behaviors. Given that self-regulation entails work and that work requires energy, people should be less capable of self-regulating when oxygen levels are lower, rather than higher, than what is needed for any given task.

Understanding the link between oxygen and self-regulation is important. Evidence indicates, for instance, that impaired self-regulation increases criminality (Gottfredson & Hirschi, 1990; Pratt & Cullen, 2000) and undermines mental health (Mischel, Shoda, & Peake, 1988; Shoda, Mischel, & Peake, 1990; Tangney, Baumeister, & Boone, 2004). Hence, understanding how oxygen levels influence self-regulation could potentially reduce criminality and improve mental health. For example, improving air quality in cities so as to improve oxygen levels could reduce the number of murders, and regulating oxygen levels at the workplace could be used to reduce worker burnout.

Self-Regulation Relies On A Depletable Energy

Ample evidence demonstrates that self-regulation relies on energy that can be used up by self-regulating. First, people often report feeling psychologically fatigued after self-regulating (e.g., dieting, quitting smoking) (Baumeister, Heatherton, & Tice, 1994), as if self-regulating had used up energy. Second, people are more likely to fail at self-regulation in the evening and later hours than during earlier parts of the day (Baumeister et al., 1994), as if an energy is reduced during people's daily activities. Third, numerous experimental studies demonstrate that, after having self-regulated on an initial task (e.g., resisting the temptation of eating cookies), people are prone to fail at later tasks requiring self-regulation (e.g., suppressing laughter) (Baumeister, Gailliot, DeWall, & Oaten, 2006). It is as if the initial self-regulatory task uses up energy needed to perform well on the later task. These effects have been found on a variety of tasks, including emotion regulation, thought suppression, mental persistence, dietary restraint, sexual restraint, monetary restraint, aggressive restraint, controlling attention, stereotype suppression, interracial interactions, ostracism, rejection, stereotype threat, passivity, decision making, and logical reasoning (Baumeister et al., 2006).

If self-regulation relies on a depletable energy, then it is likely that at least part of this energy is derived from glucose, oxygen, or both, given that they are vital in allowing the psyche to function. Indeed, an assortment of evidence from various scientific disciplines suggests that self-regulating can reduce glucose in the bloodstream, thereby impairing self-regulation later on (Fairclough & Houston, 2004; Gailliot et al., 2007; Gailliot & Baumeister, 2007). For instance, one study linked low glucose with increased aggression (which stems from poor self-regulation; DeWall, Baumeister, Stillman, & Gailliot, 2007;

Stucke & Baumeister, 2006) among children (Benton, Brett, & Brain, 1987). Thus, self-regulation relies on an energy that is depleted with use, and it appears that glucose is part of this energy. When glucose is low, people are less capable of self-regulating.

Self-Regulation and Oxygen

Self-regulation is impaired when glucose levels are low and is facilitated when glucose levels are high (at least up to a point). Is self-regulation influenced by oxygen in a similar fashion? Some evidence suggests that it might. A few studies have found that providing supplementary oxygen improves performance on memory, attentional vigilance, and intelligence tasks (Edwards & Hart 1974; Moss & Scholey 1996; Neubauer, Gottlieb, & Pevsner, 1994; Winder & Borrill, 1998). For instance, participants who breathed 100% oxygen for 1 minute performed better on word recall tasks and an attentional-vigilance task, compared to participants who breathed room air (Moss, Scholey, & Wesnes, 1998). There is a high degree of overlap between cognitive processes underlying performance on these tasks and those underlying self-regulation (see Schmeichel, Gailliot, & Baumeister, 2005; Schmeichel, 2007), and therefore self-regulation might also benefit from supplementary oxygen.

Other studies have provided converging evidence that oxygen levels influence cognitive performance. In one, sailors were confined in a hypobaric chamber for fifteen days in which they were exposed to varying oxygen levels and completed various cognitive tasks (Shukitt, Burse, Banderet, Knight, & Cymerman, 1988). Performance on these tasks generally was impaired at the lowest oxygen levels. In another study, army volunteers exhibited impaired performance on various cognitive tasks at simulated higher altitudes (oxygen levels are reduced at higher altitudes), but giving the volunteers supplementary oxygen eliminated these impairments (Crowley et al., 1992). A study by Gerard (2000) provided similar results, such that supplementary oxygen at simulated high altitudes resulted in faster reaction times on a cognitive task. Last, Terry (2001) had participants complete a divided attention task at 10,000 feet (high oxygen levels) and 14,000 feet (low oxygen levels). Participants performed more poorly on the task at 14,000 feet than at 10,000 feet. Thus, some evidence suggests that oxygen levels might influence self-regulatory performance, to the extent that self-regulation relies on similar mechanisms as other cognitive tasks.

Overview of the Current Studies

Two studies tested whether oxygen levels influence self-regulatory performance. In Study 1, participants completed a self-regulatory task (the Stroop task) while breathing air with either ambient or decreased oxygen levels. In Study 2, participants completed a self-regulatory task (a measure of prejudice) while breathing air with either decreased, increased, or ambient oxygen levels. It was predicted that higher oxygen levels would improve self-regulation, whereas lower oxygen levels would impair self-regulation.

Study 1

In Study 1, participants completed the Stroop task while breathing through paper bags that either did or did not have holes in them that allowed ambient air to pass through freely. The Stroop task requires that participants self-regulate by overriding the tendency to read words, instead to state the color ink in which words appear. Breathing through a paper bag without holes should increase the carbon dioxide content in the bag and thus, decrease the oxygen content (e.g., see American Heart Association, 1977; Gorman et al., 1984), whereas breathing though a bag with holes should not alter the oxygen content. Participants completed the Stroop task twice, once while breathing through the bag with holes and once while breathing through the bag without holes. It was predicted that participants would perform worse on the Stroop (slower reaction times and/or decreased accuracy) while breathing through the bag without holes than with holes, presumably because of the reduced oxygen levels in the bag without holes.

Method

Participants

Participants were 76 undergraduates (47 women, 29 men, 1 unreported) enrolled in an introductory psychology course. Excluded from this tally and from all analyses were two female participants who responded incorrectly to greater than 91% of trials. Participants received credit toward fulfilling a course requirement for their participation and were randomly assigned to counterbalancing condition.

Procedure

Participants were told that the study was examining the relationship between air content and performance on cognitive tasks. First, participants completed 60 practice Stroop trials on the computer. For these trials, a string of Xs ("XXXXX") appeared on the computer screen in either red, green, or blue colored font. Participants were asked to indicate the color of the Xs by pushing, as quickly as possible, one of three buttons on the keyboard. Immediately following each response, the next string of Xs appeared.

After the practice trials, participants completed 2 blocks of 60 trials in which the word *red*, *blue*, or *green* appeared on the computer screen in either red, blue, or green colored font. Participants were asked to indicate the font color by pressing one of three buttons on the keyboard that matched the font color of the words. They were asked to respond as quickly and accurately as possible. While completing these trials, participants breathed through a paper bag that either did or did not have the bottom of the bag removed so as to allow ambient air to pass through freely. Participants breathed through one bag for the first block of trials and the other bag for the second block of trials (the order of which was counterbalanced across participants). The bag was held up by a breathing mask apparatus.

Results and Discussion

Two 2 (Paper bag: With vs. Without holes) X 2 (Order of bags: Bag with holes first vs. Bag without holes first) mixed-factorial repeated measures analysis of variances (MANOVAs) were used to analyze Stroop performance (i.e., reaction times and number of errors). The analyses indicated that the main effect of paper bag condition was not significant for either reaction times or number of errors, *F*s < 1, *ns*. The analyses indicated a

Table 1: *Stroop Performance as a Function of Paper Bag and Counterbalancing Conditions (Study 1)*

	Bag without Hole (Low Oxygen)	Bag with Hole (Normal Oxygen)
Reaction Times		
Low oxygen first	1.13 (0.17)	1.01 (0.14)
Normal oxygen first	1.04 (0.23)	1.17 (0.26)
Errors		
Low oxygen first	2.71 (2.74)	1.76 (1.79)
Normal oxygen first	1.65 (1.82)	3.03 (2.75)

significant interaction between paper bag condition and order of the bags for both reaction times, $F\ (1,\ 74) = 61.21$, $p < .001$, and number of errors, $F\ (1,\ 74) = 19.91$, $p < .001$. Participants performed better on the second set of Stroop trials than the first regardless of which paper bag they were breathing through (see Table 1), most likely because of a practice effect.

These results reject the hypothesis that oxygen levels influence self-regulation. Breathing through a paper bag without holes, and hence breathing air with reduced oxygen levels, did not influence self-regulation (Stroop performance), compared to breathing through a paper bag with holes, and hence breathing air with normal oxygen levels.

Study 2

Study 2 provided a better test than Study 1 of the hypothesis that oxygen levels influence self-regulation by both increasing and decreasing oxygen levels. Specifically, participants completed a measure of prejudice toward homosexuals while breathing air with differential oxygen content. Stifling prejudice requires self-regulation (Richeson & Shelton, 2003; Richeson & Trawalter, 2005) and, therefore, expressing higher levels of prejudice is indicative of worse self-regulation. To manipulate oxygen content, participants breathed through a paper bag (which is known to increase carbon dioxide and thus, decrease oxygen) that either did or did not have holes (as in Study 1) and that either did or did not have supplementary oxygen supplied to it. It was predicted that participants would express less prejudice as the oxygen content in the air increased. Thus, participants who breathed through the bag with holes that contained supplementary oxygen should exhibit the lowest prejudice levels, participants who breathed through the bag without holes and without supplementary oxygen should exhibit the highest prejudice levels, and the other two groups of participants should exhibit moderate levels of prejudice.

Method

Participants

Participants were 124 undergraduates (64 women, 60 men) enrolled in an introductory psychology course. They received credit toward fulfilling a course requirement for their participation. Participants were randomly assigned to condition.

Procedure

Participants were told that the study was examining the relationship between air content and attitudes. First, they completed a pre-measure of attitudes toward homosexuals by being asked to imagine two men, identical in all respects except in their sexual orientation (heterosexual vs. homosexual), and then to indicate the extent to which they would like the two men, using a scale from 1 (*I'd like the heterosexual much more than the homosexual*) to 9 (*I'd like the homosexual much more than the heterosexual*), with 5 (*I'd like the two men to the same extent*) as the midpoint. The purpose of including the pre-measure was to account for additional variability in the final measure of prejudice.

After the pre-measure, participants placed the paper bag around their mouths. The bag either did or did not have the bottom removed from it (as in Study 1), and either did or did not have supplementary oxygen flowing through it. The supplementary oxygen was delivered via a plastic tube from an oxygen concentrator. For participants who received supplementary oxygen, the concentrator was set so that it increased the oxygen content in the air from 21% (ambient room oxygen content) to approximately 30%. For participants who did not receive supplementary oxygen, the concentrator supplied air with 21% oxygen content to the bag.

Participants breathed through the bag for 1 minute. Then, while still breathing through the bag, they completed the Heterosexual Attitudes Toward Homosexuals (HATH) scale (Larsen, Reed, & Hoffman, 1980), as a measure of prejudice toward homosexuals. The HATH contains 20 items (e.g., "All homosexuality bars should be closed down.") answered on a scale from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). After completing the HATH, participants completed the Brief Mood Introspection Scale (BMIS; Mayer & Gaschke, 1988), a measure of mood and arousal, to examine whether the oxygen manipulations influenced mood or arousal, thus providing a potential alternative explanation as to why the oxygen manipulations might influence prejudice. Participants did not indicate their sexual orientation.

Results and Discussion

HATH scores were subjected to a 2 (Paper bag: With vs. Without bottom) X 2 (Supplementary oxygen: Oxygen vs. No oxygen) between-subjects analysis of covariance, with liking ratings included as a covariate. The analysis indicated a non-significant trend for paper bag condition, $F(1, 119) = 2.97$, $p = .09$, such that having the bottom of the bag removed somewhat increased prejudice (see Table 2). This result contradicts the hypothesis that breathing through the intact bag would increase prejudice (due to decreased oxygen content). The main effect for oxygen condition also was non-significant, $F(1, 119) = 2.25$,

Table 2: *Prejudice as a Function of Paper Bag and Oxygen Conditions (Study 2)*

	Bag without Hole (Low Oxygen)	**Bag with Hole (Normal Oxygen)**
Supplementary oxygen	2.08 (0.73)	2.21 (0.78)
Normal oxygen	1.85 (0.55)	2.10 (0.75)

$p = .14$, and in the opposite direction as predicted, such that receiving supplementary oxygen was associated with higher prejudice. The interaction did not approach significance, $F < 1$, *ns*.

These results argue against the idea that oxygen helps reduce prejudice. Although no significant results emerged, the pattern of means suggested that, if anything, oxygen might increase prejudice. Breathing through a paper bag, and hence air with decreased oxygen, was marginally associated with increased prejudice, as was receiving supplementary oxygen. It is unclear why this pattern of results emerged.

Mood and arousal scores from the BMIS were subjected to a 2 (Paper bag: With vs. Without holes) X 2 (Supplementary oxygen: Oxygen vs. No oxygen) mixed-factorial MANOVA. This analysis produced no significant results, Fs < 1, *ns*. This indicates that changes in oxygen content do not influence mood or arousal, which is somewhat of a moot point, given that the manipulations did not influence prejudice.

General Discussion

Self-regulation is an important ability across the lifespan, but it is also very effortful and prone to failure. Prior research indicates that self-regulation relies on glucose as a depletable energy source (e.g., Gailliot et al., 2007), consistent with the idea that the ability to work is proportional to the amount of energy available to perform that work. Glucose is part of the energy that allows for self-regulatory work, yet the psyche exists not only because of the brain's use of glucose but also oxygen. Hence, the proposed studies examined whether oxygen levels, like glucose levels, influence self-regulatory performance. It was predicted that oxygen would be important to successful self-regulation, such that lower, rather than higher, oxygen levels would undermine Stroop performance (Study 1) and increase prejudice (Study 2). The results largely disconfirmed these hypotheses, however. Breathing air with reduced, rather than ambient, oxygen levels (i.e., breathing through a paper bag that was intact, rather than one that had the bottom removed) produced no discernible effects on Stroop performance (Study 1), and manipulating oxygen levels via a paper bag and oxygen concentrator produced no reliable effects on prejudice (Study 2). These results directly contradict the hypotheses, suggesting that somewhat minor changes in oxygen levels achieved by the current manipulations do not influence self-regulatory abilities.

Though it is unclear why oxygen had little effect in these studies, different methods might produce different effects. It is likely that more dramatic changes in oxygen should influence self-regulation and, indeed, extremely low oxygen levels surely would impair selfregulation as one approaches unconsciousness. Past work in which participants breathed air comprised solely of oxygen, for instance, found that the additional oxygen improved cognitive performance (e.g., Moss, Scholey, & Wesnes, 1998). Oxygen might have influenced selfregulation had the current work increased oxygen levels above 30% (e.g., Study 2) or decreased them more dramatically. The time one breathes the air with manipulated oxygen content might also be influential. Had participants breathed the air for differing amounts of time in the current studies, effects may have emerged under some, albeit unknown, conditions. Another methodological improvement would be to verify that the manipulations actually influenced air content, such as by having an external air monitor that indicates ambient oxygen levels. It is also plausible that oxygen might be most influential when people are mentally fatigued or depleted.

Self-Regulation and Energy

A variety of evidence indicates that self-regulation relies on an energy source that is depleted with use (e.g., Baumeister et al., 2006). Initial experimental evidence and work from scientific disciplines primarily outside of psychology suggest that glucose is an important part of this energy source (Gailliot et al., 2007; Gailliot & Baumeister, 2007), whereas the current studies suggest that oxygen might be less relevant to the energy dynamics of self-control. Future efforts to understand self-regulation that focus on glucose might prove more fruitful than those that focus on oxygen.

Other issues concerning self-regulation and energy warrant attention. One is a link between arousal and self-regulation. Arousal is, by definition, a high energy state, and so one might expect that people should have stellar self-control when highly aroused. Arousal has been found to heighten people's automatic responses (Zajonc, 1965), however, which seems the opposite of self-control, given that self-control often entails overriding automatic responses. There is some evidence suggesting that high arousal might increase other forms of poor selfcontrol, such as aggression (Zillmann, Katcher, & Milavsky, 1972) and stealing (Diener et al., 1976). Does this contradict the idea that self-control benefits from having more energy? Possibly not. Energy in the mind and body performs a variety of work, much of which can be irrelevant to self-regulation. Hence, it is possible that, during a high arousal state, the brain and body are working quite well (e.g., processing anxious concerns), but the work being performed is irrelevant to or even detrimental to self-control. If so, then future research efforts should focus on the particular situations and forms of energy that influence self-regulation.

A second issue concerns the distinction between potential energy (i.e., the future capacity to perform work) and kinetic energy (i.e., the existence of energy in currently usable form). How might this distinction relate to self-regulation? From a psychological perspective, glucose and perhaps oxygen should be considered potential energies, because, in biological form, they represent the future capacity to work. Eating a healthy meal and hence having a reliable store of glucose, for instance, can be seen as having potential energy that will be used to keep one functioning throughout the day, and taking in a breath of fresh air can be viewed as potential energy in the lungs that will soon give rise to psychological meaning.

Concluding Remarks

After witnessing a science experiment on air in the 1600's, King Charles II and the royal court laughed with silliness, exclaiming, "anyone can see that there is nothing in air…" (Sorbjan, 1996). Although this view is quite comical today to scholars in the physical sciences, who have shown that the air is anything but empty, the court's remarks might hold some bit of truth, as far as psychologists are concerned. The current work found that oxygen in the air had no significant influence on self-regulation. The air certainly is teeming with molecular content and activity, but its dynamics might have only a trivial influence on psychological processes in people's day to day lives. In terms of psychological theorizing, the air indeed may be empty.

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