Using behavioral interventions to reduce single-use produce bags

Yu Luo[1] and Jiaying Zhao[1,2]

[1]Department of Psychology, University of British Columbia
[2]Institute for Resources, Environment and Sustainability, University of British Columbia

Please address correspondence to:

Jiaying Zhao
Department of Psychology
Institute for Resources, Environment and Sustainability
University of British Columbia
Vancouver, B.C., Canada, V6T 1Z4

Abstract

Plastic pollution has become a major conservation challenge. Current policies have primarily focused on plastic bags but neglected produce bags which are a pervasive source of packaging in grocery stores. Here we designed and tested 12 behavioral interventions with 3,893 participants in a simulated shopping task. Each intervention reduced produce bag use by 9.2% to 48.7%. Specifically, interventions using a financial incentive or punishment (extrinsic motivation), showing the social norm (intrinsic motivation), reminding people the positive consequence of not using produce bags (memory), and drawing attention to the no produce bag option (attention) were the most effective. Moreover, these interventions were more effective for liberal individuals than conservatives or independents. Finally, interventions that reduced decision friction were more effective than those that increased decision friction. These findings provide new evidence for which behavioral interventions are effective and for which population, with implications for designing behavioral strategies to curb plastic pollution.

Keywords: plastic pollution, behavior change, nudge, sludge, experiments

Using behavioral interventions to reduce single-use produce bags

Plastic pollution has become a major conservation challenge in recent decades. At a global scale, 29 million metric tons of plastic waste entered aquatic and terrestrial environments in 2016, and the annual rate was estimated to increase 2.8-fold by 2040 in a business-as-usual scenario (Lau et al., 2020). One major source of plastic waste is plastic bags. To address plastic pollution, many countries and municipalities have introduced a levy on plastic bags or banned the use of plastic bags along with non-legislative interventions such as campaigns to raise awareness of plastic pollution (Schnurr et al., 2018). Although plastic bags have been targeted extensively, single-use produce bags which are a common form of packaging in grocery stores around the world, have received little attention. Produce bags are usually free and often used by consumers to pack fruits, vegetables, or bulk foods in grocery stores. Produce bags can be more problematic than plastic bags since some studies have argued that thicker plastic bags can be reused (Muposhi et al., 2022), whereas produce bags cannot.

While a number of factors have been identified to influence plastic consumption (e.g., convenience, social norms, incentives; Heidbreder et al., 2019; Nuojua et al., 2022), it is currently unknown which intervention is the most effective at reducing single-use produce bags. Moreover, an emerging literature suggests that the same intervention has heterogeneous effects for different groups (Bryan et al., 2021). For example, people with centrist or right-leaning political orientations respond less strongly to interventions promoting climate action (Luo & Zhao, 2019) or reducing plastic waste than people with left-leaning orientation (Davison et al., 2021). Thus, any behavioral intervention targeting plastic pollution needs to consider the heterogeneous effects on different populations.

To curb single-use produce bag use, we designed and tested 12 behavioral interventions targeting six cognitive factors to reduce produce bag use in a simulated grocery shopping task. These behavioral interventions were motivated by a new cognitive framework that categorized behavioral interventions along six cognitive processes: attention, perception, memory, effort, intrinsic motivation, and extrinsic motivation (Luo et al., 2021). For example, an intervention targeting attention is highlighting the rising global temperature which was found to increase pro-climate actions in liberal individuals (Luo & Zhao, 2019). An intervention targeting perception is showing a marine animal (e.g., a turtle) trapped in plastic debris which was found to reduce plastic waste (Luo et al., 2022). An intervention targeting memory is a reminder that highlights the environmental consequences which reduced food waste (Barker et al., 2021). An effort intervention is moving the recycling bins closer to people's doors which increased recycling rates by over 130% (DiGiacomo et al., 2018). An intrinsic motivation intervention is showing a social norm message that highlights the behaviors of other people, which increased towel reuse behavior (Goldstein et al., 2008). An extrinsic motivation intervention is showing the financial incentive or punishment of an action, a common example being applying a small fee to deter plastic bag use (T. A. Homonoff, 2018). It is currently unknown which of the six types of interventions is the most effective at reducing plastic waste.

In addition to the six cognitive factors, the cognitive framework distinguished nudge interventions (i.e., those that reduce decision friction) and sludge interventions (i.e., those that increase decision friction), thus forming 12 categories of behavioral interventions (Luo et al., 2021; Mills, 2020; Sunstein, 2019). An example nudge intervention to reduce plastic waste is to provide a small financial incentive for recycling plastic bottles, and an example sludge intervention to reduce plastic waste is to impose a small fee for using plastic bags. It is also

currently unknown whether nudge interventions or sludge interventions are more effective at reducing plastic waste. The current study thus aims to fill the previous knowledge gaps by identifying which of the 12 behavioral interventions is the most effective at reducing produce bag consumption using a randomized controlled trial. This study is an attempt to tease out which cognitive factor is relevant for plastic consumption and for which population (e.g., liberals, conservatives). It also provides a new methodology to simultaneously test different interventions organized along a cognitive framework to influence one behavioral outcome of produce bag consumption.

Methods

Participants

A total of 3,893 participants (2,107 female; mean age=38.3 years, SD=11.8) from Amazon Mechanical Turk in the U.S. participated in the study for US $0.25. Participants who failed the attention check or provided a number which was above 2.5 standard deviations of the mean number of produce bags (outliers) were excluded from the study, leaving a final sample of 3,591 participants.

Stimuli and Procedure

Participants were randomly assigned to one of the 13 conditions (12 intervention conditions and a control condition). In all conditions, participants were asked to buy groceries at an online store. The screen showed 18 images of fresh fruits and vegetables in a 3x6 matrix. After selecting the items, they proceeded to the checkout page where they saw a roll of produce bags and reported the number of produce bags they needed to pack the produce they purchased.

The nudge interventions were designed to facilitate the choice of not using produce bags by reducing friction (Figure 1a-f). In attention nudge, we added a checkbox and highlighted the

label “I don’t need a produce bag” in red to draw participants’ attention. In perception nudge, we used an image of a turtle in a clean marine environment. In memory nudge, we reminded participants that if they chose to not use produce bags, the impact of plastic pollution on the ocean would be reduced. In effort nudge, a zero was shown in the input box for the number of produce bags as the default. In intrinsic motivation nudge, a social norm message asked participants to join their fellow citizens to not use produce bags. In extrinsic motivation nudge, participants were informed that if they chose to not use the produce bag, we would donate to an environmental organization.

The sludge interventions were designed to deter participants from using produce bags by increasing friction (Figure 1g-l). In attention sludge, if participants chose to use produce bags, they would see an “Are you sure” pop-out alert asking them to confirm their choice. In perception sludge, an image of a turtle eating plastic debris was shown to emphasize the harmful consequences associated with plastic pollution. In memory sludge, we reminded participants that the impacts of plastic pollution on the ocean would increase if they use produce bags. In effort sludge, participants who would like to use produce bags had to first click on an additional checkbox. In intrinsic motivation sludge, a social norm messaging stated that a minority of fellow citizens chose to use produce bags. In extrinsic motivation sludge, participants were informed that if they chose to use produce bags, we would not donate to the environmental organization. The control condition did not use any intervention and just asked participants how many produce bags they needed.

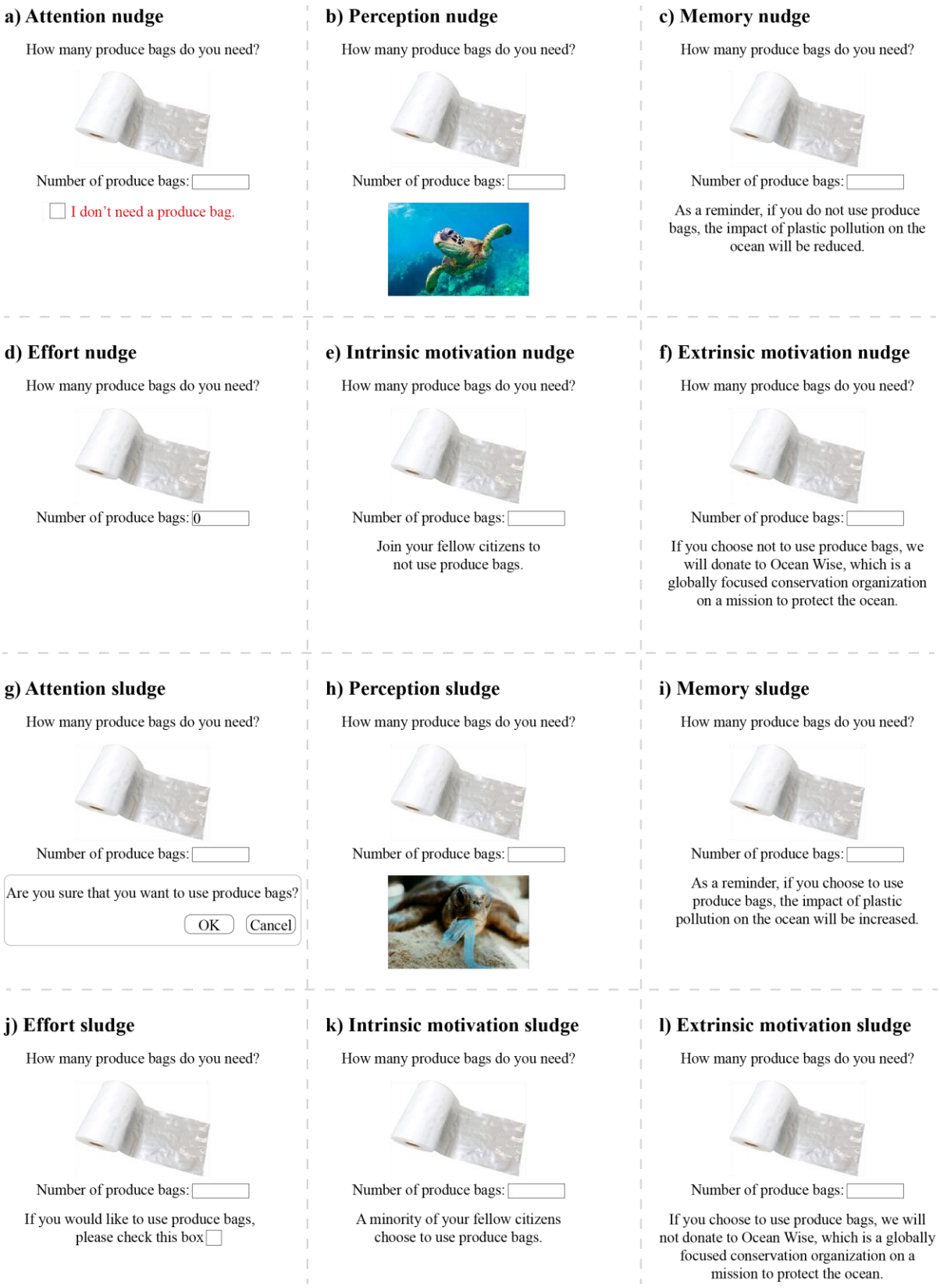

Figure 1: a-f) Design of the six nudge interventions; g-l) Designs of the six sludge interventions.

After checkout, participants in all conditions answered a few demographic questions and reported their political orientation on an 11-point scale from −5 (very liberal) to 5 (very conservative). In our analysis, participants were divided into liberals (below 0, N=1,077), independents (at 0, N=684), conservatives (above 0, N=1,830). Participants also rated their climate concerns, how environmentally friendly the produce bags are, how likely they will use produce bags in general, and how likely other people will use produce bags in general.

Results

A one-way ANCOVA assessed the differences in produce bag consumption across the 13 conditions while controlling for demographic factors such as age, gender, political orientation, and climate concerns (see Table S1 in Supplementary Materials). There was a significant difference between the 13 conditions [$F(12, 3569)=6.88$, $p<.001$, $\eta_p^2=.014$]. Dunnett's post-hoc tests revealed that participants in the extrinsic nudge (48.7% reduction, $p<.001$), extrinsic sludge (45.4% reduction, $p<.001$), memory nudge (37.8% reduction, $p=.04$), intrinsic nudge (35.1% reduction, $p<.001$), attention nudge (34.6% reduction, $p=.001$), and memory sludge (27% reduction, $p=.02$) conditions requested significantly fewer produce bags than those in the control condition (**Figure** a, Table S2). Although the other interventions were not significantly different from the control condition (p's>.07), participants in these conditions requested between 9.2% to 23% fewer produce bags than those in the control condition (Table S3). These results show that the most effective interventions to reduce produce bags were using a financial incentive or punishment (extrinsic motivation), reminding participants the positive consequence of not using produce bags (memory), showing a social norm message (intrinsic motivation), drawing attention to the "I don't need a produce bag" option (attention), and reminding participant the negative consequence of using produce bags (memory).

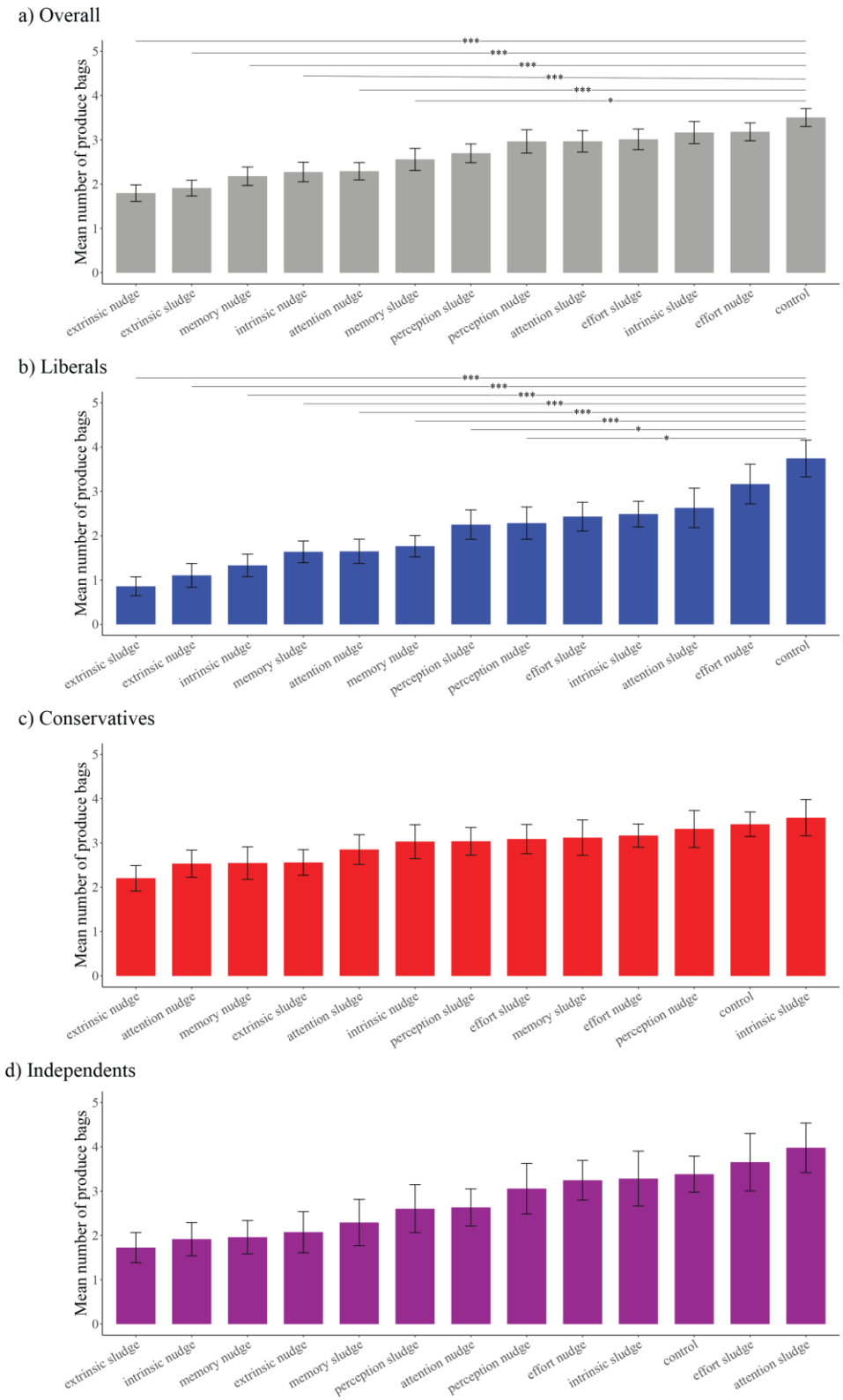

Figure 2: Mean number of produce bags in the intervention conditions and in the control condition for (a) all participants (N=3,591), (b) liberals (N=1,077), (c) conservatives (N=1,830), and (d) independents (N=684). (Error bars reflect ±1 SEM; **p*<.05, ****p*<.001)

We further grouped participants into liberals, conservatives, and independents based on their self-reported political orientation and examined the effectiveness of the interventions in each group. For liberals (N=1,077, **Figure** b), the same ANCOVA showed that there was a significant difference between conditions [$F(12, 1055)=7.70$, $p<.001$, $\eta_p^2=.06$] (Table S1). Dunnett's post-hoc tests revealed that liberals in the extrinsic sludge (77.1% reduction, $p=.001$), extrinsic nudge (70.5% reduction, $p=.001$), intrinsic nudge (64.5% reduction, $p=.001$), memory sludge (56.3% reduction, $p=.001$), attention nudge (56.0% reduction, $p=.001$), memory nudge (52.9% reduction, $p=.001$), perception sludge (39.9.1% reduction, $p=.01$), and perception nudge (39.0% reduction, $p=.02$) conditions requested significantly less produce bags than those in the control condition (Table S2). Liberals in all other interventions requested numerically fewer produce bags than those in the control condition (15.4% to 35.1% reduction, p's>.05, Table S4). However, for conservatives (N=1,830, **Figure** c) the ANCOVA showed no significant difference between conditions [$F(12, 1809)=1.52$, $p<.001$, $\eta_p^2=.008$] (Table S1, Table S5). For independents (N=684, **Figure** d), there was a significant difference between conditions [$F(12, 663)=2.71$, $p=.001$, $\eta_p^2=.026$] (Table S1), but Dunnett's post-hoc tests showed that none of the interventions was significantly different from the control condition (p's>.09, Table S2, Table S6). Therefore, the behavioral interventions showed the strongest effects in liberal participants, and no effects in conservative or independent participants.

Furthermore, we conducted a 2 (type of intervention: nudge vs. sludge) x 6 (cognitive process: attention, perception, memory, effort, intrinsic motivation, and extrinsic motivation) ANCOVA to examine differences between the cognitive factors and intervention type while controlling for demographic factors (Figure 3a).

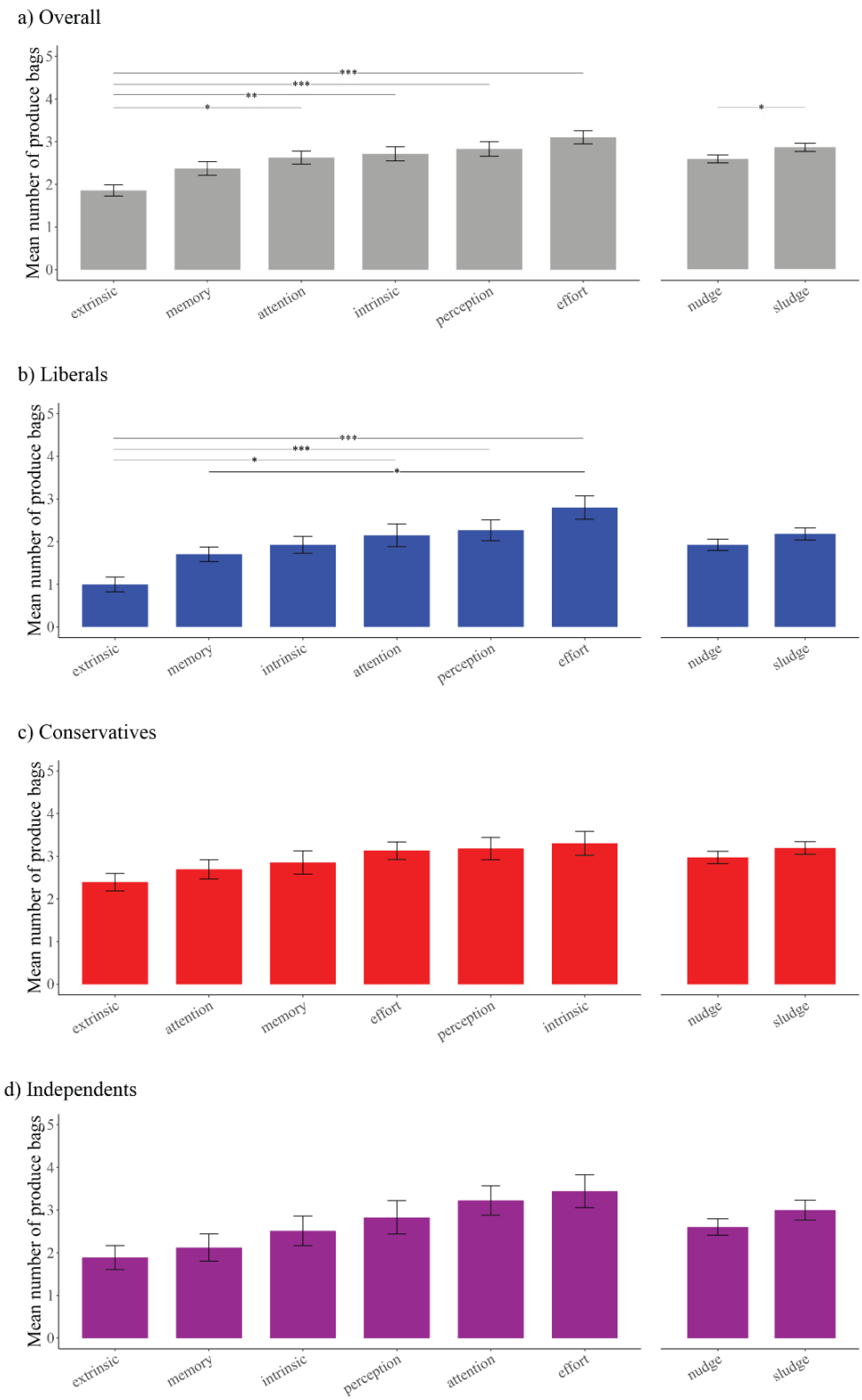

Figure 3. Comparisons of mean number of produce bags used across the six cognitive processes and between the two types of intervention (nudge vs. sludge) for (a) all participants (N=3,591), (b) liberals (N=1,077), (c) conservatives (N=1,830), and (d) independents (N=684). (Error bars reflect ±1 SEM; **p*<.05, ***p*<.01, ****p*<.001).

The two-way ANCOVA showed that nudge interventions had a larger impact than sludge interventions [$F(5,3288)=9.00$, $p<.001$, $\eta_p^2=0.008$], that there was a significant main effect of type of intervention [$F(1,3288)=4.68$, $p=.03$, $\eta_p^2=0.0008$] and a significant interaction [$F(5,3288)=2.39$, $p=.04$, $\eta_p^2=0.004$] (Table S7, Table S8). Post-hoc Tukey results revealed that extrinsic motivation interventions were significantly more effective than effort ($p<.001$), perception ($p<.001$), intrinsic motivation ($p=.005$), and attention ($p=.03$) interventions (Figure 3a). None of the other pairwise comparisons was significant (p's>0.11, Table S9).

For liberals (Figure b), there was a significant effect of cognitive process [$F(5,978)=8.75$, $p<.001$, $\eta_p^2=0.03$] and a significant interaction [$F(5,978)=2.45$, $p=.03$, $\eta_p^2=0.01$] but no effect of type of intervention [$F(1,978)=2.23$, $p=.13$, $\eta_p^2=0.0006$] (Table S7, Table S8). Post-hoc Tukey results revealed that extrinsic motivation interventions were significantly more effective than effort ($p<.001$), perception ($p<.003$), and attention interventions ($p=.048$). Also, memory interventions were more effective than effort interventions ($p=.03$, Table S9). For conservatives (Figure 3c), there was a significant effect of cognitive process [$F(5,1661)=2.27$, $p=.045$, $\eta_p^2=0.005$] but no effect of type of intervention [$F(1,1661)=1.27$, $p=.26$, $\eta_p^2=0.001$] or interaction [$F(5,1661)=0.54$, $p=.74$, $\eta_p^2=0.002$] (Table S7, Table S8), and none of the post-hoc comparisons were significant (p's>.07, Table S9). For independents (Figure 3d), there was a significant effect of cognitive process [$F(5,609)=3.90$, $p=.001$, $\eta_p^2=0.02$] but no effect of type of intervention [$F(1, 609)=2.13$, $p=.14$, $\eta_p^2=0.0004$] or interaction [$F(5, 609)=1.13$, $p=.34$, $\eta_p^2=0.009$] (Table S7, Table S8), and none of the post-hoc comparisons were significant (p's>.07, Table S9).

General Discussion

The current study examined the impact of 12 behavioral interventions on reducing produce bag consumption in a simulated grocery shopping task. We found that the most effective

interventions to reduce produce bags were providing a financial incentive or punishment (extrinsic motivation), reminding participants the positive or negative consequences of produce bags (memory), showing a social norm message (intrinsic motivation), and drawing attention to the no bag option (attention). Each of the 12 interventions reduced the number of produce bags by 9.2% to 48.7% compared to the control condition. Moreover, these behavioral interventions were more effective for liberal participants than for conservatives and independents, revealing heterogeneous effects of the interventions for people with different political orientations. These findings suggest that tailored interventions to different sociopolitical groups should be considered to reduce produce bag consumption (Mills, 2022; Zhao & Luo, 2021).

Across the six cognitive factors, interventions targeting extrinsic motivation were more effective than interventions targeting attention, perception, intrinsic motivation, and effort. This suggests that a financial incentive of not using produce bags or punishment of using produce bags may be more important to participants than simply drawing attention to the no bag option, visualizing the marine consequences of produce bags, showing the social norms, or changing the effort involved in this task. The success of extrinsic motivation interventions could be due to a number of reasons. First, it highlights the financial consequences (i.e., no donations to Ocean Wise) of produce bag consumption, even though these financial consequences do not apply directly to the participants themselves. The explicit consequences give participants a reason to not use produce bags, whereas the other interventions (except for memory interventions) do not mention any explicit consequences of their actions. Second, the financial consequences may resemble the plastic bag fees with which participants may be familiar. The participants may have generalized from not using plastic bags to avoid the fee to not using produce bags to ensure the donation. Finally, the extrinsic motivation interventions are the only ones that involved a third

party (i.e., Ocean Wise), which may elicit a sense of guilt in the participants if their use of produce bags results in no donations to the organization.

The extrinsic sludge intervention that imposed a financial punishment by not donating to Ocean Wise for using produce bags was consistent with previous studies showing that imposing a small fee on plastic bags significantly decreased the number of plastic bags used at grocery stores (Convery et al., 2007; T. Homonoff et al., 2018). Interestingly, providing a financial incentive by donating to Ocean Wise for not using produce bags seemed to be more effective than imposing a financial punishment in the current study. This was consistent with a recent study that showed that donating to a charity for customers who did not purchase single-use carrier bags significantly reduced plastic bag consumption (Romano & Sotis, 2021).

Extrinsic motivation interventions were not significantly different from memory interventions that reminded people the environmental consequences of produce bags. This is perhaps not surprising because the memory interventions highlighted the non-financial benefits or costs of produce bags, which could be related to the financial benefits or costs. Both the extrinsic motivation interventions (i.e., donating or not donating to an environmental organization) and memory interventions (i.e., reminding the positive or negative consequences of plastic pollution) explicitly described the consequences of participants' choices, whereas the other interventions provided guidance toward reducing produce bag use without providing a justification. Moreover, reminding participants the positive effect of not using produce bags seemed to be more effective than reminding people the negative consequence of produce bag consumption, which was again consistent with past studies where reminding people the benefits of not eating meat significantly reduced meat consumption (Wolstenholme et al., 2020).

The intrinsic motivation nudge intervention was also effective at reducing produce bag consumption compared to the control condition, consistent with a theoretical model showing that descriptive norm was the strongest predictor of plastic avoidance (Borg et al., 2020). The attention nudge intervention enhanced the attentional salience of the option of not using any produce bags, consistent with past studies where drawing attention to vehicle inspection increased inspection rates (Namazu et al., 2018), or highlighting the message of renewing license plate stickers significantly increased the likelihood of license renewal among drivers (Castelo et al., 2015). Lastly for liberals, both positive and negative visualization of a turtle in the ocean were effective, consistent with past studies that showed that the impact of plastics on marine animals elicited the motivation to reduce plastic waste (Boomsma et al., 2016; Luo et al., 2022).

Nudge interventions were overall more effective than sludge interventions in reducing produce bag use. This finding was consistent with the previous meta-analyses showing that interventions that eased decision making were the most effective in the environmental domain (Luo et al., 2021; Mertens et al., 2022). This suggests that behavioral strategies to reduce plastic waste should make the decision to not use produce bags easier rather than making the decision to use produce bags harder. This said, we found effort interventions were the least effective in our study. One explanation is that we asked a simple question where participants indicated how many produce bags they needed, an action that required minimum effort compared to other actions involving physically recycling waste or sorting items into bins. Thus, decreasing the amount of effort by making 0 produce bags as the default or increasing effort by requiring participants to check a checkbox if they wanted to use produce bags may not have a meaningful impact on the action compared to reducing the physical or cognitive effort of reducing plastic

waste in past experiments (e.g., walking a longer distance to recycle, DiGiacomo et al., 2018; sorting items into bins, Wu et al., 2018).

The current study is significant for several reasons. First, it offers novel theoretical insights on which cognitive factors (e.g., extrinsic motivation, memory, attention) are important in shaping produce bag consumption. It provides first experimental evidence for which behavioral interventions guided by which cognitive factors are effective at reducing produce bag consumption compared to the control condition without any intervention. Second, it offers new evidence on the efficacy of nudge vs. sludge interventions in reducing produce bag use. This suggests that behavioral interventions should try to reduce decision friction rather than increasing it. Third, the findings demonstrate the heterogeneity of the intervention effects where liberal participants showed the strongest effects of the behavioral interventions, compared to conservative or independent participants. This suggests that behavioral interventions can be used with liberal participants who tend to be more environmentally conscious, but perhaps not with conservative or independent participants, with whom other approaches should be considered. Fourth, the study offers an experimental paradigm to simultaneously examine the impacts of different interventions on a single behavioral outcome. Finally, the findings provide practical guidance for practitioners (e.g., grocery stores) to develop behaviorally informed strategies to curb produce bag consumption. For example, grocery stores can either highlight the financial and environmental costs of produce bags, or highlight the financial and environmental benefits of not using produce bags, to discourage consumers from using produce bags. Signage can be posted beside the produce bags to remind consumers that using fewer produce bags can help reduce plastic pollution in the ocean, ask people to bring reusable produce bags, or display the impacts of produce bags on marine animals.

In conclusion, the current study showed that a number of behavioral interventions can effectively reduce produce bag consumption. Although the current study was conducted on a simulated grocery store platform, it demonstrates a promise in the potential impact of nudge and sludge interventions. Future studies should assess the impact of these behavioral interventions on produce bags in actual grocery stores. These findings provide new insights on which cognitive insights can impact produce bag consumption.

Acknowledgments

We thank Sarah Da Silva for providing helpful comments and support. This work was supported by the Canada Research Chairs program (to JZ), Social Sciences and Humanities Research Council (SSHRC) Doctoral Fellowship (to YL), and a grant from Environment and Climate Change Canada (GCXE21E006 to JZ and YL).

References

Barker, H., Shaw, P. J., Richards, B., Clegg, Z., & Smith, D. (2021). What Nudge Techniques Work for Food Waste Behaviour Change at the Consumer Level? A Systematic Review. *Sustainability*. *13*(19), 11099. https://doi.org/10.3390/su131911099

Boomsma, C., Pahl, S., & Andrade, J. (2016). Imagining Change: An Integrative Approach toward Explaining the Motivational Role of Mental Imagery in Pro-environmental Behavior. *Frontiers in Psychology*, *7*, 1780-1780. https://doi.org/10.3389/fpsyg.2016.01780

Borg, K., Curtis, J., & Lindsay, J. (2020). Social norms and plastic avoidance: Testing the theory of normative social behaviour on an environmental behaviour. *Journal of Consumer Behaviour*, *19*(6), 594–607. https://doi.org/10.1002/cb.1842

Bryan, C. J., Tipton, E., & Yeager, D. S. (2021). Behavioural science is unlikely to change the world without a heterogeneity revolution. *Nature Human Behaviour*, *5*(8), 980–989. https://doi.org/10.1038/s41562-021-01143-3

Castelo, N., Hardy, E.A., House, J., Mazar, N., Tsai, C.I., & Zhao, M. (2015). Moving citizens online: Using salience & message framing to motivate behavior change. *Behavioral Science & Policy*, *1*, 57 - 68.

Convery, F., McDonnell, S., & Ferreira, S. (2007). The most popular tax in Europe? Lessons from the Irish plastic bags levy. *Environmental and Resource Economics*, *38*(1), 1–11. https://doi.org/10.1007/s10640-006-9059-2

Davison, S. M. C., White, M. P., Pahl, S., Taylor, T., Fielding, K., Roberts, B. R., Economou, T., McMeel, O., Kellett, P., & Fleming, L. E. (2021). Public concern about, and desire for research into, the human health effects of marine plastic pollution: Results from a 15-country survey across Europe and Australia. *Global Environmental Change*, *69*, 102309.

https://doi.org/https://doi.org/10.1016/j.gloenvcha.2021.102309

DiGiacomo, A., Wu, D. W. L., Lenkic, P., Fraser, B., Zhao, J., & Kingstone, A. (2018). Convenience improves composting and recycling rates in high-density residential buildings. *Journal of Environmental Planning and Management*, *61*(2), 309–331. https://doi.org/10.1080/09640568.2017.1305332

Goldstein, N. J., Cialdini, R. B., & Griskevicius, V. (2008). A room with a viewpoint: Using social norms to motivate environmental conservation in hotels. *Journal of Consumer Research*, *35*(3), 472–482. https://doi.org/10.1086/586910

Heidbreder, L. M., Bablok, I., Drews, S., & Menzel, C. (2019). Tackling the plastic problem: A review on perceptions, behaviors, and interventions. *Science of The Total Environment*, *668*, 1077–1093. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.02.437

Homonoff, T. A. (2018). Can small incentives have large effects? the impact of taxes versus bonuses on disposable bag use. *American Economic Journal. Economic Policy*, *10*(4), 177-210. https://doi.org/10.1257/pol.20150261

Homonoff, T., Kao, L.-S., Palmer, D., & Seybolt, C. (2018). Skipping The Bag: Assessing the impact of Chicago's tax on disposable bags Tatiana. In *Ideas42. org*. http://www.ideas42.org/wp-content/uploads/2018/09/Bag_Tax_Paper_final.pdf

Lau, W. W. Y., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., Velis, C. A., Godfrey, L., Boucher, J., Murphy, M. B., Thompson, R. C., Jankowska, E., Castillo, A. C., Pilditch, T. D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet, J., … Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. *Science*, *369*(6509), 1455–1461. https://doi.org/10.1126/SCIENCE.ABA9475

Luo, Y., Douglas, J., Pahl, S., & Zhao, J. (2022). Reducing Plastic Waste by Visualizing Marine

Consequences. *Environment and Behavior*, *54*(4), 809–832. https://doi.org/10.1177/00139165221090154

Luo, Y., Soman, D., & Zhao, J. (2021). *A meta-analytic cognitive framework of nudge and sludge*. psyarxiv.com. https://psyarxiv.com/dbmu3/

Luo, Y., & Zhao, J. (2019). Motivated attention in climate change perception and action. *Frontiers in Psychology, 10*, 1541-1541. https://doi.org/10.3389/fpsyg.2019.01541

Mertens, S., Herberz, M., Hahnel, U. J. J., & Brosch, T. (2022). The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(1), 1–10. https://doi.org/10.1073/pnas.2107346118

Mills, S. (2020). Nudge/sludge symmetry: on the relationship between nudge and sludge and the resulting ontological, normative and transparency implications. *Behavioural Public Policy*, 1–24. https://doi.org/10.1017/bpp.2020.61

Mills, S. (2022). Personalized nudging. *Behavioural Public Policy, 6*(1), 150–159. https://doi.org/10.1017/bpp.2020.7

Muposhi, A., Mpinganjira, M., & Wait, M. (2022). Considerations, benefits and unintended consequences of banning plastic shopping bags for environmental sustainability: A systematic literature review. *Waste Management and Research*, *40*(3), 248–261. https://doi.org/10.1177/0734242X211003965

Namazu, M., Zhao, J., & Dowlatabadi, H. (2016;2018;). Nudging for responsible carsharing: Using behavioral economics to change transportation behavior. *Transportation, 45*(1), 105-119. https://doi.org/10.1007/s11116-016-9727-1

Nuojua, S., Cracknell, D., & Pahl, S. (2022). Human Behavior and Marine Plastic

Pollution. *Plastics and the Ocean: Origin, Characterization, Fate, and Impacts*, 429-454.

Romano, A., & Sotis, C. (2021). Odi et Amo: A nudge to reduce the consumption of single-use carrier bags. *Waste Management*, *120*, 382–391. https://doi.org/https://doi.org/10.1016/j.wasman.2020.09.021

Schnurr, R. E. J., Alboiu, V., Chaudhary, M., Corbett, R. A., Quanz, M. E., Sankar, K., Srain, H. S., Thavarajah, V., Xanthos, D., & Walker, T. R. (2018). Reducing marine pollution from single-use plastics (SUPs): A review. *Marine Pollution Bulletin, 137,* 157-171. https://doi.org/10.1016/j.marpolbul.2018.10.001

Sunstein, C. R. (2019). Sludge Audits. *Behavioural Public Policy*, 1–20. https://doi.org/DOI: 10.1017/bpp.2019.32

Wolstenholme, E., Poortinga, W., & Whitmarsh, L. (2020). Two Birds, One Stone: The Effectiveness of Health and Environmental Messages to Reduce Meat Consumption and Encourage Pro-environmental Behavioral Spillover. *Frontiers in Psychology*, *11*, 577111. https://doi.org/10.3389/fpsyg.2020.577111

Wu, D. W. -L., Lenkic, P. J., DiGiacomo, A., Cech, P., Zhao, J., & Kingstone, A. (2018). How does the design of waste disposal signage influence waste disposal behavior? *Journal of Environmental Psychology, 58,* 77-85. https://doi.org/10.1016/j.jenvp.2018.07.009

Zhao, J., & Luo, Y. (2021). A framework to address cognitive biases of climate change. *Neuron*, *109*(22), 3548–3551. https://doi.org/10.1016/j.neuron.2021.08.029

Supplementary Materials

A. Additional results for one-way ANCOVA

Table S1.

One-way ANCOVA results for all participants, liberals, conservatives, and independents.

Source	Overall	Liberals	Conservatives	Independents
Condition	$F(12, 3569)=6.88$, $p<.001$, $\eta_p^2=0.01$	$F(12, 1055)=7.70$, $p<.001$, $\eta_p^2=0.06$	$F(12, 1809)=1.52$, $p=.108$, $\eta_p^2=0.01$	$F(12, 663)=2.71$, $p=.001$, $\eta_p^2=0.03$
Age	$F(1, 3569)=0.27$, $p=.604$, $\eta_p^2<0.01$	$F(1, 1055)=0.72$, $p=.395$, $\eta_p^2<0.01$	$F(1, 1809)=0.15$, $p=.703$, $\eta_p^2=0.00$	$F(1, 663)=0.66$, $p=.416$, $\eta_p^2<0.01$
Gender (female=0, male=1)	$F(2, 3569)=0.46$, $p=.631$, $\eta_p^2=0.00$	$F(2, 1055)=0.63$, $p=.531$, $\eta_p^2<0.01$	$F(1, 1809)=0.00$, $p=.98$, $\eta_p^2=0.00$	$F(2, 663)=0.63$, $p=.535$, $\eta_p^2=0.00$
How likely other people will use produce bags (1=very unlikely, 5=very likely)	$F(1, 3569)=83.78$, $p<.001$, $\eta_p^2=0.00$	$F(1, 1055)=10.16$, $p=.001$, $\eta_p^2=0.01$	$F(1, 1809)=95.15$, $p<.001$, $\eta_p^2=0.00$	$F(1, 663)=3.34$, $p=.068$, $\eta_p^2=0.01$
How environmentally friendly the produce bags are (1=not at all, 5=extremely)	$F(1, 3569)=106.56$, $p<.001$, $\eta_p^2=0.00$	$F(1, 1055)=12.00$, $p<.001$, $\eta_p^2=0.00$	$F(1, 1809)=27.80$, $p<.001$, $\eta_p^2=0.01$	$F(1, 663)=23.26$, $p<.001$, $\eta_p^2=0.01$
How likely they will use produce bags (1=very unlikely, 5=very likely)	$F(1, 3569)=272.18$, $p<.001$, $\eta_p^2=0.07$	$F(1, 1055)=160.23$, $p<.001$, $\eta_p^2=0.13$	$F(1, 1809)=69.47$, $p<.001$, $\eta_p^2=0.04$	$F(1, 663)=76.61$, $p<.001$, $\eta_p^2=0.10$
Political orientation (-5=very liberal, 5=very conservative)	$F(1, 3569)=2.68$, $p=.102$, $\eta_p^2<0.01$	$F(1, 1055)=1.13$, $p=.288$, $\eta_p^2<0.01$	$F(1, 1809)=2.00$, $p=.158$, $\eta_p^2=0.00$	NA
Climate concern (1=dismissive, 6=alarmed)	$F(1, 3569)=7.61$, $p=.006$, $\eta_p^2<0.01$	$F(1, 1055)=18.78$, $p<.001$, $\eta_p^2=0.02$	$F(1, 1809)=0.80$, $p=.372$, $\eta_p^2=0.00$	$F(1, 663)=0.10$, $p=.752$, $\eta_p^2=-0.00$
Total number of items selected in the shopping task	$F(1, 3569)=128.37$, $p<.001$, $\eta_p^2=0.03$	$F(1, 1055)=43.42$, $p<.001$, $\eta_p^2=0.04$	$F(1, 1809)=59.98$, $p<.001$, $\eta_p^2=0.03$	$F(1, 663)=32.45$, $p<.001$, $\eta_p^2=0.00$

Note. Condition is the primary outcome, and the other variables are covariates. Non-categorical variables were standardized.

Table S2.

Post-hoc Dunnett's comparisons between each condition and the control.

Comparison	Overall	Liberals	Conservatives	Independents
extrinsic nudge-control	<.001***	<.001***	.1	.33
extrinsic sludge-control	<.001***	<.001***	.41	.09
memory nudge-control	<.001***	<.001***	.42	.26
intrinsic nudge-control	<.001***	<.001***	.99	.19
attention nudge-control	<.001***	<.001***	.38	.99
memory sludge-control	.02**	<.001***	1.00	.59
perception sludge-control	.07	.01**	.99	.89
perception nudge-control	.46	.02**	1.00	1.00
attention sludge-control	.47	.12	.86	.99
effort sludge-control	.60	.05	1.00	1.00
intrinsic sludge-control	.92	.05	1.00	1.00
effort nudge-control	.93	.85	1.00	1.00

Note. The *p*-values of the comparison between each condition and the control are shown for all participants, liberals, conservatives, and independents (**p<.01, ***p<.001).

Table S3.

Descriptive statistics of the number of produce bags used in each condition for all participants (N=3,893).

Condition	Mean	SD	N	% Change
extrinsic nudge	1.80	3.10	277	-48.7
extrinsic sludge	1.91	3.00	282	-45.4
memory nudge	2.18	3.41	269	-37.8
intrinsic nudge	2.27	3.67	278	-35.1
attention nudge	2.29	3.25	278	-34.6
memory sludge	2.56	4.11	274	-27.0
perception sludge	2.70	3.54	280	-23.0
perception nudge	2.96	4.37	276	-15.4
attention sludge	2.97	3.99	272	-15.3
effort sludge	3.01	3.73	257	-14.0
intrinsic sludge	3.18	3.46	273	-9.7
effort nudge	3.16	4.13	293	-9.2
control	3.50	3.39	282	0.0

Note. The mean number of produce bags used, standard deviation, number of participants, and percent of change relative to the control condition are shown.

Table S4.

Descriptive statistics of the number of produce bags in each condition for liberal participants (N=1,077).

Condition	Mean	SD	N	% Change
extrinsic sludge	0.86	1.87	77	-77.1
extrinsic nudge	1.10	2.63	96	-70.5
intrinsic nudge	1.33	2.35	85	-64.5
memory sludge	1.64	2.15	77	-56.3
attention nudge	1.65	2.49	82	-56.0
memory nudge	1.76	2.27	89	-52.9
perception sludge	2.25	3.18	92	-39.9
perception nudge	2.28	3.28	81	-39.0
effort sludge	2.43	2.75	72	-35.1
intrinsic sludge	2.49	2.75	90	-33.5
attention sludge	2.63	4.12	86	-29.8
effort nudge	3.17	3.79	72	-15.4
control	3.74	3.67	78	0.0

Note. The mean number of produce bags used, standard deviation, number of participants, and percent of change relative to the control condition are shown.

Table S5.

Descriptive statistics of the number of produce bags in each condition for conservative participants (N=1,830).

Condition	Mean	SD	N	% Change
extrinsic nudge	2.20	3.23	127	-35.6
attention nudge	2.53	3.62	139	-26.0
memory nudge	2.55	4.20	130	-25.6
extrinsic sludge	2.56	3.43	143	-25.2
attention sludge	2.85	3.97	141	-16.7
intrinsic nudge	3.03	4.44	134	-11.5
perception sludge	3.04	3.61	135	-11.3
effort sludge	3.09	3.85	136	-9.8
memory sludge	3.12	4.89	149	-8.8
effort nudge	3.17	3.39	168	-7.5
perception nudge	3.32	4.95	142	-3.1
control	3.42	3.38	149	0.0
intrinsic sludge	3.57	4.79	137	+4.3

Note. The mean number of produce bags used, standard deviation, number of participants, and percent of change relative to the control condition are shown.

Table S6.

Descriptive statistics of the number of produce bags in each condition for independent participants (N=684).

Condition	Mean	SD	N	% Change
extrinsic sludge	1.73	2.68	62	-49.0
intrinsic nudge	1.92	2.88	59	-43.4
memory nudge	1.96	2.66	50	-42.0
extrinsic nudge	2.07	3.40	54	-38.7
memory sludge	2.29	3.62	48	-32.2
perception sludge	2.6	3.94	53	-23.0
attention nudge	2.63	3.17	57	-22.2
perception nudge	3.06	4.15	53	-9.6
effort nudge	3.25	3.26	53	-4.0
intrinsic sludge	3.28	4.20	46	-2.9
control	3.38	3.03	55	0.0
effort sludge	3.65	4.54	49	+8.0
attention sludge	3.98	3.75	45	+17.6

Note. The mean number of produce bags used, standard deviation, number of participants, and percent of change relative to the control condition are shown.

B. Additional results for two-way ANCOVA

Table S7.

Two-way ANCOVA results for all participants, liberals, conservatives, and independents.

Source	Overall	Liberals	Conservatives	Independents
Type of intervention	$F(1, 3288)=4.68$, $p=0.031$, $\eta_p^2<0.01$	$F(1, 978)=2.22$, $p=0.136$, $\eta_p^2<0.01$	$F(1, 1661)=1.27$, $p=0.26$, $\eta_p^2<0.01$	$F(1, 609)=2.13$, $p=0.145$, $\eta_p^2<0.01$
Cognitive process	$F(5, 3288)=9.02$, $p<.001$, $\eta_p^2=0.01$	$F(5, 978)=8.75$, $p<.001$, $\eta_p^2=0.03$	$F(5, 1661)=2.27$, $p=0.045$, $\eta_p^2=0.01$	$F(5, 609)=3.90$, $p<0.012$, $\eta_p^2=0.02$
Age	$F(1, 3288)=0.34$, $p=0.561$, $\eta_p^2<0.01$	$F(1, 978)=0.50$, $p=0.481$, $\eta_p^2<0.01$	$F(1, 1661)=0.17$, $p=0.678$, $\eta_p^2<0.01$	$F(1, 609)=1.38$, $p=0.241$, $\eta_p^2<0.01$
Gender (female=0, male=1)	$F(2, 3288)=0.63$, $p=0.534$, $\eta_p^2<0.01$	$F(2, 978)=0.87$, $p=0.419$, $\eta_p^2<0.01$	$F(1, 1661)=0.03$, $p=0.868$, $\eta_p^2<0.01$	$F(2, 609)=0.37$, $p=0.688$, $\eta_p^2<0.01$
How likely other people will use produce bags (1=very unlikely, 5=very likely)	$F(1, 3288)=69.03$, $p<.001$, $\eta_p^2<0.01$	$F(1, 978)=7.76$, $p<0.015$, $\eta_p^2=0.01$	$F(1, 1661)=77.37$, $p<.001$, $\eta_p^2<0.01$	$F(1, 609)=4.67$, $p=0.031$, $\eta_p^2<0.01$
How environmentally friendly the produce bags are (1=not at all, 5=extremely)	$F(1, 3288)=113.82$, $p<.001$, $\eta_p^2<0.01$	$F(1, 978)=14.61$, $p<.001$, $\eta_p^2<0.01$	$F(1, 1661)=28.95$, $p<.001$, $\eta_p^2=0.01$	$F(1, 609)=26.44$, $p<.001$, $\eta_p^2=0.02$
How likely they will use produce bags (1=very unlikely, 5=very likely)	$F(1, 3288)=265.09$, $p<.001$, $\eta_p^2=0.07$	$F(1, 978)=178.87$, $p<.001$, $\eta_p^2=0.14$	$F(1, 1661)=65.27$, $p<.001$, $\eta_p^2=0.04$	$F(1, 609)=69.86$, $p<.001$, $\eta_p^2=0.11$
Political orientation (-5=very liberal, 5=very conservative)	$F(1, 3288)=3.32$, $p=0.069$, $\eta_p^2<0.01$	$F(1, 978)=1.03$, $p=0.311$, $\eta_p^2<0.01$	$F(1, 1661)=2.42$, $p=0.12$, $\eta_p^2<0.01$	NA
Climate concern (1=dismissive, 6=alarmed)	$F(1, 3288)=4.74$, $p=0.029$, $\eta_p^2<0.01$	$F(1, 978)=12.92$, $p<.001$, $\eta_p^2=0.01$	$F(1, 1661)=0.45$, $p=0.503$, $\eta_p^2<0.01$	$F(1, 609)=0.34$, $p=0.56$, $\eta_p^2=-0.00$
Total number of items selected	$F(1, 3288)=107.84$, $p<.001$, $\eta_p^2=0.03$	$F(1, 978)=35.63$, $p<.001$, $\eta_p^2=0.04$	$F(1, 1661)=49.92$, $p<.001$, $\eta_p^2=0.03$	$F(1, 609)=30.62$, $p<.001$, $\eta_p^2<0.01$
Type of intervention : cognitive process	$F(5, 3288)=2.39$, $p=0.036$, $\eta_p^2<0.01$	$F(5, 978)=2.45$, $p=0.032$, $\eta_p^2=0.01$	$F(5, 1661)=0.54$, $p=0.743$, $\eta_p^2<0.01$	$F(5, 609)=1.13$, $p=0.345$, $\eta_p^2=0.05$

Note. The primary outcomes are the type of intervention (nudge vs. sludge) and the six cognitive processes. The other variables are covariates. Non-categorical variables were standardized.

Table S8.

Descriptive statistics of the number of produce bags by cognitive process and by intervention type.

		Overall	Liberals	Conservatives	Independents
Cognitive process					
	extrinsic	1.86 (3.05)	0.99 (2.32)	2.39 (3.34)	1.89 (3.03)
	memory	2.37 (3.78)	1.70 (2.21)	2.85 (4.58)	2.12 (3.16)
	attention	2.63 (3.65)	2.15 (3.44)	2.69 (3.80)	3.23 (3.49)
	intrinsic	2.72 (3.93)	1.93 (2.62)	3.30 (4.62)	2.51 (3.57)
	perception	2.83 (3.98)	2.27 (3.21)	3.18 (4.34)	2.83 (4.03)
	effort	3.10 (3.59)	2.80 (3.32)	3.13 (3.60)	3.44 (3.91)
Intervention type					
	nudge	2.46 (3.59)	1.83 (2.88)	2.82 (4.02)	2.48 (3.30)
	sludge	2.71 (3.79)	2.07 (2.98)	3.03 (4.13)	2.85 (3.84)

Note. The first number is the mean number of produce bags used, and the second number in the bracket is the standard deviation.

Table S9.

Post-hoc Tukey's comparisons between cognitive processes.

Comparison	Overall	Liberals	Conservatives	Independents
extrinsic-effort	<.001***	<.001***	.54	.07
extrinsic-perception	<.001***	.001**	.32	.17
extrinsic-intrinsic	.001**	.20	.07	.87
extrinsic-attention	.03**	.048*	.80	.44
extrinsic-memory	.11	.42	.38	.99
memory-effort	.46	.03*	1.00	.34
memory-perception	.69	.46	1.00	.57
memory-intrinsic	.92	1.00	.97	1.00
memory-attention	1.00	.93	.99	.86
attention-effort	.75	.29	1.00	.95
attention-perception	.92	.96	.97	1.00
attention-intrinsic	.99	.99	.69	.98
intrinsic-effort	.96	.08	.88	.61
intrinsic-perception	1.00	.70	.98	.84
perception-effort	1.00	.78	1.00	1.00

Note. The *p*-values of the comparison between cognitive processes are shown for all participants, liberals, conservatives, and independents (*p<.05, **p<.01, ***p<.001).