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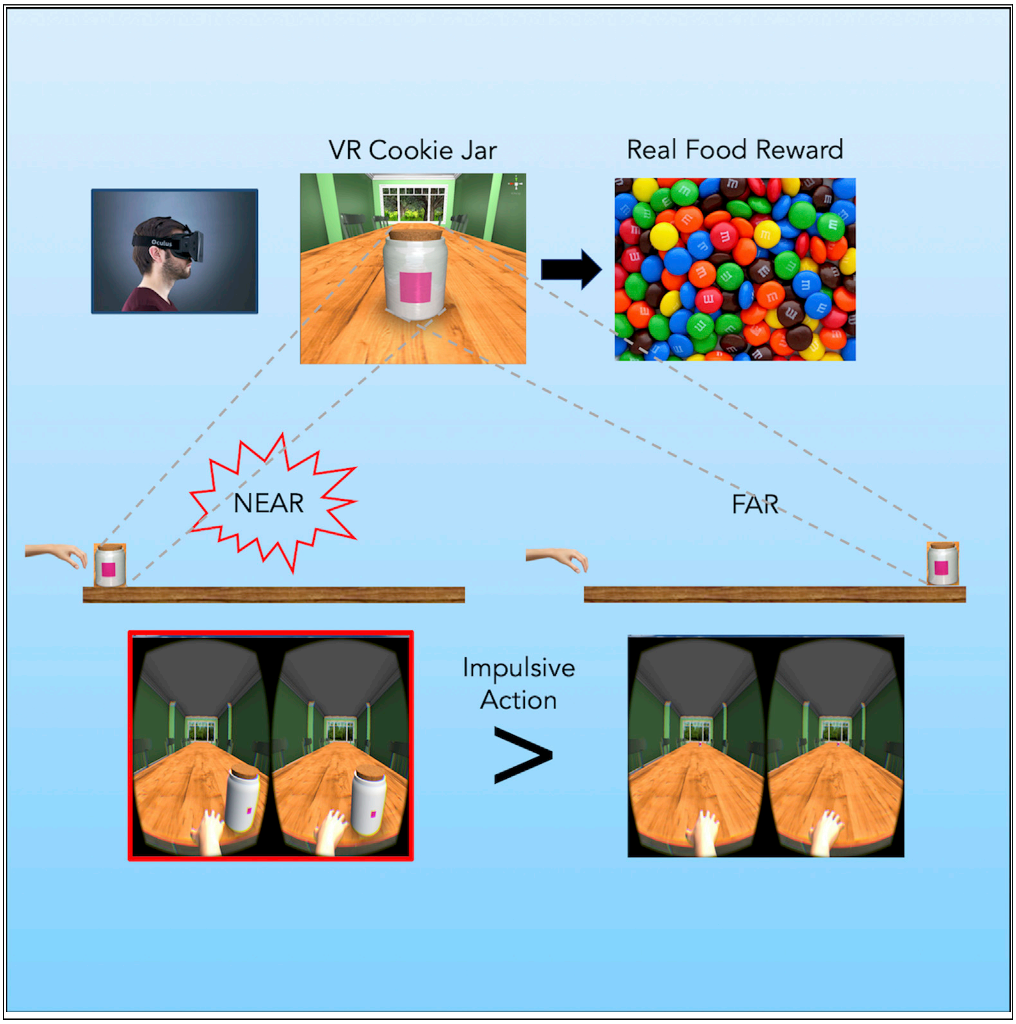

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Highlights

Proximity to rewarding cues can alter human behavior

Humans are less able to stop motor actions when rewarding cues are within reach

Results highlight the adverse role of environmental factors on impulsivity

Factors that change as objects move closer in the real world were controlled using VR

O'Connor et al., iScience *24*, 102292
April 23, 2021
https://doi.org/10.1016/j.isci.2021.102292

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Rewards that are near increase impulsive action

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SUMMARY

In modern society, the natural drive to behave impulsively in order to obtain rewards must often be curbed. A continued failure to do so is associated with a range of outcomes including drug abuse, pathological gambling, and obesity. Here, we used virtual reality technology to investigate whether spatial proximity to rewards has the power to exacerbate the drive to behave impulsively toward them. We embedded two behavioral tasks measuring distinct forms of impulsive behavior, impulsive action, and impulsive choice, within an environment rendered in virtual reality. Participants responded to three-dimensional cues representing food rewards located in either near or far space. Bayesian analyses revealed that participants were significantly less able to stop motor actions when rewarding cues were near compared with when they were far. Since factors normally associated with proximity were controlled for, these results suggest that proximity plays a distinctive role in driving impulsive actions for rewards.

INTRODUCTION

In a classic experiment, children were shown to frequently forgo the prospect of eating two marshmallows in the near future by failing to resist the temptation of eating one that is immediately available (Mischel and Shoda, 1989b). Against the backdrop of most of human history, in which humans foraged for scarce resources in competitive environments (Hill et al., 2011; Mischel and Shoda, 1989a), this human tendency to behave impulsively could be viewed as adaptive (Stevens and Stephens, 2010). In the modern world, however, where humans are increasingly exposed to an abundance of rewarding stimuli, this same tendency is linked to an array of maladaptive behaviors ranging from drug abuse (Ersche et al., 2010; Perry and Carroll, 2008) to pathological gambling (Leeman and Potenza, 2011; Miedl et al., 2014).

Perhaps the most pressing issue arising from how human impulsivity interacts with a reward-rich environment relates to eating behavior. Although an understanding of the biological underpinnings of obesity is invaluable (Clement et al., 1998; Smith and Robbins, 2012), this alone cannot explain its dramatic global rise over recent decades (Swinburn et al., 2011). As the search for underlying causes grows more pertinent, the potency of a toxic or obesogenic environment, in which access to highly palatable, energy-dense foods has become increasingly easy, is now implicated as a chief culprit (Hill et al., 2003; Lake and Townshend, 2016; Walker and Foreyt, 1999).

Could spatial proximity to available rewards play a distinctive role in amplifying this environmental toxicity? Recently, in the field of neuroscience, spatial proximity specifically has been posited as a key modulator in the role that dopamine plays on human action control irrespective of associated savings in costs such as effort expenditure (Westbrook and Frank, 2018). Research in humans, demonstrating improvements in simple perceptual decisions for monetarily rewarding cues when they are near, gives some support to this notion (O'Connor et al., 2014). Moreover, research showing that rodents impulsively approach food rewards that are near even when effort and temporal delay are greater than more distant alternatives (Morrison and Nicola, 2014), raises the possibility that spatial proximity may exert a special influence on human impulsive behavior. Yet, despite knowledge of associations between impulsive behavior and aspects of food intake such as overeating and obesity (Mole et al., 2014; Schag et al., 2013a; Velázquez-Sánchez et al., 2014), it is unclear as to whether proximity, by amplifying the inherent influence of alluring food items, exerts a potentially adverse impact on impulsive behavior.

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https://doi.org/10.1016/j.isci.2021.102292

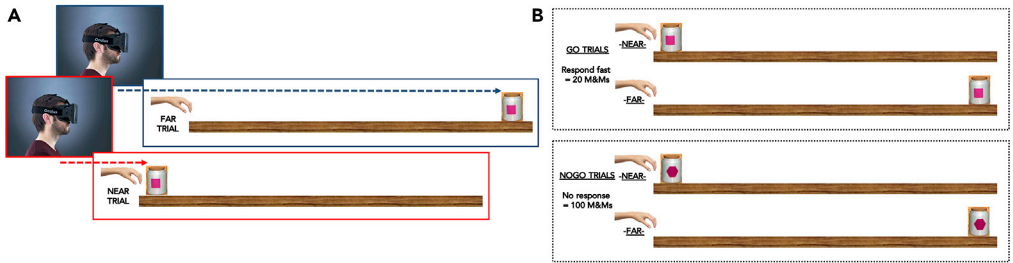

Figure 1. Basic distance manipulation and Experiment 1 task design

(A) Basic distance manipulation. Stimuli in both Experiments 1 and 2 took the form of jars containing an appetitive food (chocolate M&Ms). Binocular disparity was manipulated so that they appeared to be either near (graspable and within reach) or far (beyond reach) from participants.

(B) 3D Go/No-go task design. Participants were informed at the beginning of each experimental block which shapes would represent Go and No-go trials. When participants were presented with Go trials, in this example represented by a jar decorated with a square, they were required to respond as quickly as possible. A smaller proportion of trials consisted of No-go trials, here represented by a jar decorated with a hexagon, in which participants were required to withhold their response. Both Go and No-go trials were incentivized with appetitive food rewards (M&Ms).

Observations in naturalistic environments showing that individuals who are proximal to energy-dense foods, such as at supermarket checkouts, tend to consume more lend some support to the notion that food placement serves to enhance the toxic properties of an environment (Baskin et al., 2016; Maas et al., 2012; Musher-Eizenman et al., 2010; Privitera and Zuraikat, 2014; Rozin et al., 2011). However, by failing to disambiguate distance manipulations from their associated potential costs, such studies are, in essence, only adding to a literature demonstrating how effort and delay, as prospective and tangible costs, influence human behavior (Aronson, 1961; Croxson et al., 2009; Frederick et al., 2002; Green and Myerson, 2004; Kurniawan, 2011; Prevost et al., 2010).

By using virtual reality (VR) technology, we isolated the property of proximity in order to gauge its specific effect on impulsive behavior. Our overall hypothesis was that spatial proximity would have the effect of impairing self-control and thus increasing impulsive behavior. If such an effect exists, a primary goal of the current research was to determine the stage at which the influence of proximity is manifested. We performed two within-subject design behavioral experiments that probed distinct expressions of impulsive behavior (Dalley and Robbins, 2017; Mischel and Shoda, 1989a), both of which are known to be involved in the development and maintenance of obesity (Hill et al., 2011; Schag et al., 2013a, 2013b; Weller et al., 2008) and, more broadly, addiction (Bickel et al., 2007; Spechler et al., 2016; Stevens and Stephens, 2010), to address the following question. Does proximity increase *impulsive action*, when a rapid physical action cannot be inhibited, or does it increase *impulsive choice*, when a preference is computed to make a decision? By situating each task within a 3D immersive, yet controlled environment, we could hold irrelevant factors associated with engaging with stimuli in near/far space, namely, effort and delay as well as retinal size, constant between conditions. At the same time, we could simulate some ecological features consistent with everyday food consumption. Cues in both tasks took the form of virtual cookie jars containing an appetitive food (chocolate M&Ms) and, crucially, by modulating differences in binocular disparity, their stereoscopic properties were manipulated so that they appeared to be either near (graspable and within reach) or far (beyond reach) from participants. Thus, for both experiments, distances were programmed such that near cues were 21 cm and far cues were 360 cm from the edge of the virtual table at which participants sat (Figure 1A). We allowed the retinal size of cookie jars to vary just as they would in reality. Crucially, however, the retinal size of the shapes presented on the jars, the task-related stimuli, was held constant between conditions (see supplemental information for an in-depth explanation).

In Experiment 1, we modified a Go/No-go task, which is designed to probe impulsive action, the inability to withhold simple motor responses. Consistent with a standard Go/No-go task, participants were presented with cues that they were required to either respond to quickly (Go trials) or withhold a response (No-go trials). However, in place of standard flat 2D visual stimuli, we introduced three-dimensionality to the task so that we could determine whether proximity to Go/No-go cues has an effect on impulsive action. Thus, trials were further divided into equal numbers of Go and No-go trials that were either near or far (Figure 1B).

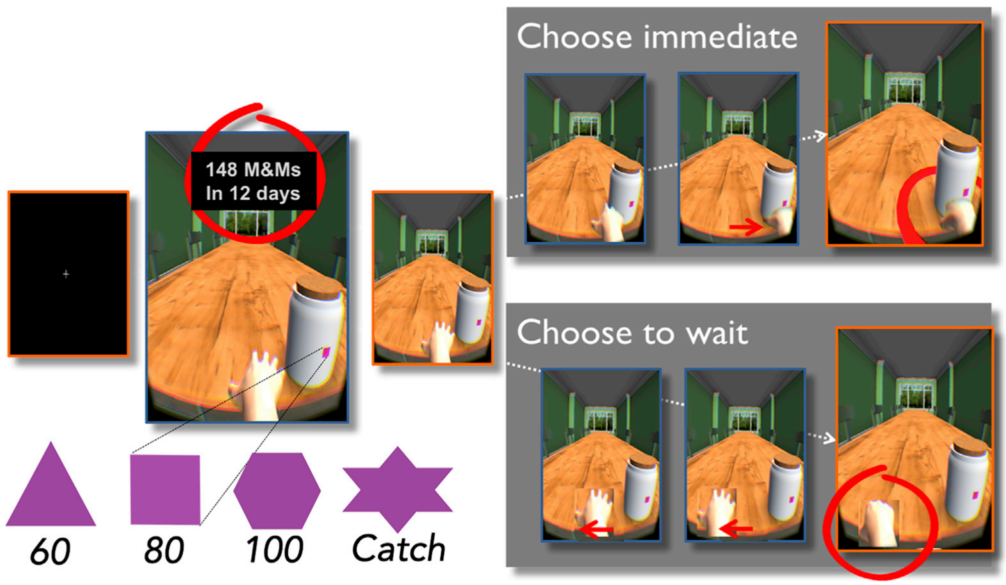

Figure 2. Experiment 2 task design

3D intertemporal choice task design (near trial example). On each trial larger-later offers were presented in word form, whereas smaller-sooner offers were represented by the shape that can be seen on the front of a cookie jar. Regardless of whether cues were near or far, participants indicated their choices (either choose immediate or wait) by moving a virtual hand either left or right.

In Experiment 2, we tested whether spatial proximity also affects impulsive choice, which can be characterized as a preference for small, more immediate rewards over larger, but delayed rewards. Consistent with a typical intertemporal choice task, participants were presented with choices associated with these outcomes. However, once again, in place of standard flat 2D visual stimuli, we introduced three-dimensionality to the task so that we could determine whether proximity to cues representing immediate reward has an effect on impulsive choice. Thus, trials were further divided into equal numbers of intertemporal choice trials in which smaller-sooner offers, those driving impulsive choice, were either near or far from participants (Figure 2). As in Experiment 1, distances were programmed such that near cues were 21 cm and far cues were 360 cm from the edge of the virtual table at which participants sat (Figure 1A).

RESULTS

Experiment 1: The effect of proximity on impulsive action

Under our hypothesis that the tendency to act impulsively would increase with proximity, we expected participants to experience more difficulty withholding their responses when appetitive No-go cues were near compared with when they were far. To investigate this, we focused on the percentage of commission errors that participants made for No-go trials within both near and far conditions. Since a commission error occurs when an individual is unable to withhold a response over a stimulus it can be said to represent the occurrence of an impulsive action. In real terms, this kind of event can be likened to grabbing one more piece of cake from the buffet table despite having previously resolved to abstain from eating any more. In this experiment, we informed participants prior to the task that, for every successful response to a Go stimulus, they could win 20 M&Ms, whereas for every withheld response for a No-go stimulus, they could win 100 M&Ms. Insufficiently rapid responses for Go stimuli resulted in no reward, whereas failures to refrain from responding in the presence of No-go stimuli were rewarded with 20 M&Ms. In this way, unsuccessful inhibitions of response were intentionally treated in the same manner as successful responses to Go trials. This reward contingency can be likened to a scenario whereby a motor action leading to the attainment of a small reward also leads to the simultaneous foregoing of a greater reward.

In line with our hypothesis, we found that participants made more commission errors when they were required to withhold responses for No-go cues that were near (42.71%) compared with when the same types of cues were far (25.73%) (Figure 3A). A Bayesian paired samples t test to compare near and far commission errors produced a very large (Cohen's *d*) effect size of 1.2 CI95% [0.72, 1.69]. A

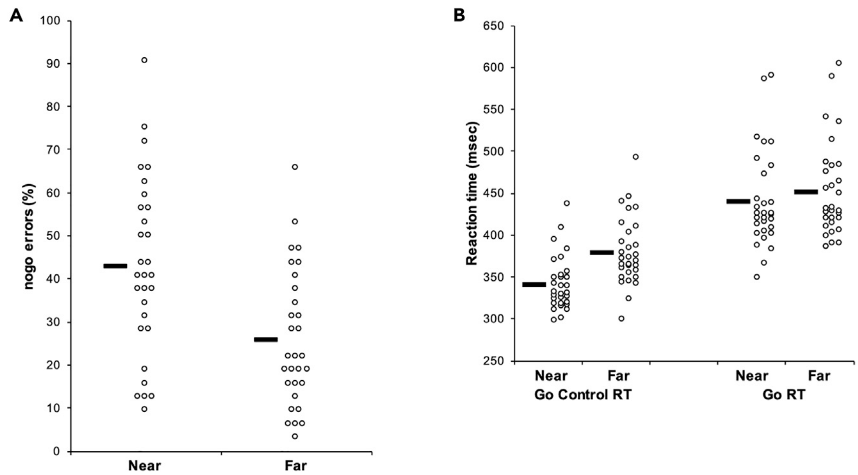

Figure 3. Experiment 1 results

(A) Univariate scatterplot of No-go commission errors percentage. Each dot represents a participant's percentage of No-go errors of commission for both near and far conditions. The y axis shows the percentage of No-go errors, and the x axis shows both near and far conditions. Black bars show the mean average of No-go errors (%) for each condition.

(B) Univariate scatterplot of Go trial and Go-Control trial response times. Each dot represents a participant's average response time for both Go and Go-Control trials under both near and far conditions. The x axis shows response time (milliseconds), and the y axis shows near and far conditions for each type of trial. Black bars show the mean average of response time (milliseconds) under each condition.

very large Bayes factor of 117,391.8 (BF10) tells us that the evidence for an effect of proximity on No-go error performance is decisive (equivalent frequentist statistics can be found in supplementary information). This finding supports the notion that proximity increases the tendency to commit impulsive actions. In the near condition, participants were less able to take advantage of the larger potential gains offered by not acting in the presence of No-go cues, instead receiving the smaller gains offered by rapid responding. Of importance, proximity was not associated with any additional savings in action costs, namely, effort and delay. In addition, we also controlled for the retinal size of task-related stimuli (see supplemental information).

Another commonly used measure obtained from the Go/No-go task is omission errors. These occur when participants do not respond to Go trials and are thought to reflect lapses of attention or vigilance (Ersche et al., 2010; Halperin et al., 1991; Perry and Carroll, 2008). In order to examine whether these processes played a role during performance of our 3D Go/No-go task, we submitted omission errors for near and far Go trials to a Bayesian paired samples t test. Although we observed a numerical difference whereby near omission errors (near, 32.38%) were slightly lower than far omission errors (far, 35.79%), this produced a small-medium effect size (Cohen's *d*) of 0.30 CI95% [0.04, 0.66]. We found no evidence that Near omission errors are different from Far omission errors (*BF10* = 0.85). The absence of any notable effect lends further support to the notion that impulsivity was the primary driver underlying differences in behavior between near and far conditions.

We also examined the speed of participants' responses for near and far Go trials. Response times were based on the initial onset of participants' movements. In addition to blocks consisting of both Go and No-go trials, we ran short blocks consisting of only near and far ''Go-Control'' trials. These Go-Control trials gave us a measure of response speeds that were uninhibited by any context of response inhibition (Criaud and Boulinguez, 2013; Leeman and Potenza, 2011; Miedl et al., 2014). Here we observed a reduction in the latency of actions when cues representing Go-Control trials were near (340.9 ms) compared with when they were far (378.9 ms) (Figure 3B left). A Bayesian paired samples t test produced a very large effect size (Cohen's *d*) of 2.31 CI95% [1.62, 3.05]. A Bayes factor of 7.64 (BF10) indicates that the evidence for the presence of faster Go-Control response times as an effect of proximity is substantial. This effect is consistent with a pattern of action commission previously observed in both humans (Clement et al., 1998; O'Connor et al., 2014; Smith and Robbins, 2012) and rodents (McGinty et al., 2013), thought to reflect dopamine-driven biases in response invigoration for proximal rewards.

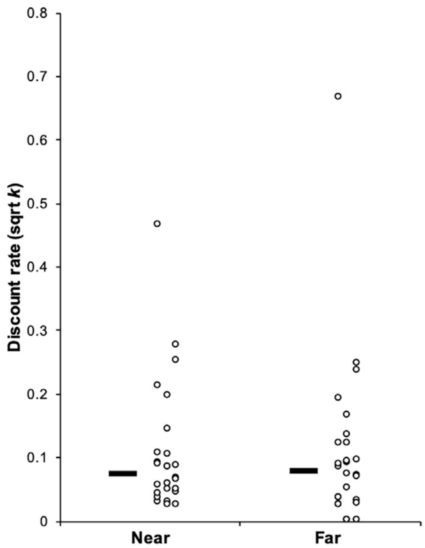

Figure 4. Experiment 2 results

Univariate scatterplot of discount rates (sqrt *k*). Each dot represents a participant's rate of impulsivity, as indexed by sqrt *k*, for both near and far conditions. The y axis shows the discount rate (sqrt *k*), and the *x* axis shows near and far conditions. Black bars show the median average of sqrt *k* under each condition.

When we examined how participants responded for all standard Go trials (those embedded within a No-go context), compared with all Go-Control trials, we observed a slowing for Go trials as participants adjusted their speeds to allow for the prospect of response inhibition. A Bayesian paired samples t test produced a very large effect size (Cohen's *d*) of 2.56 CI95% [2.17, 3.02]. A Bayes factor of 5.12 provides substantial evidence that participants slowed their responding to Go trials within a context of No-go trials (standard Go trials, 445.6 ms) compared with when there was no such context (Go-Control trials, 359.9 ms).

When comparing near and far Go trials, we also observed a reduction in the latency of actions for Go trials that were near (439.4 ms) compared with far (451.8 ms) (Figure 3B, right). A Bayesian paired samples t test produced a medium-large effect size (Cohen's *d*) of 0.52 CI95% [0.14, 0.90]. A Bayes factor of 8.88 (BF10) tells us that the evidence for the presence of faster Go trial response times as an effect of proximity is substantial. Further results demonstrating that observed impoverishments in the ability of participants to withhold responses over near cues cannot simply be explained by faster responses in corresponding near Go trials can be found in supplementary information—additional results.

Experiment 2: The effect of proximity on impulsive choice

Under our hypothesis, we expected participants to behave more impulsively when appetitive cues for smaller-sooner reward amounts were near compared with when the same kinds of cues were far from participants. With human discounting behavior being reasonably well characterized by a hyperbolic function (Green et al., 2005; Hill et al., 2003; Lake and Townshend, 2016; Walker and Foreyt, 1999), we used the hyperbolic model (Mazur, 1987; Westbrook and Frank, 2018) to obtain individual estimates of discounting rates (parameter *k*) for both near and far conditions, as a measure of impulsive choice (for detailed estimation procedures see supplemental information). Across participants we observed little difference in impulsive behavior between the near (sqrt(*k*) = −2.218) and far (sqrt(k) = −3.390) distance manipulations (Figure 4). A Bayesian paired samples t test produced a very small effect size (Cohen's *d*) of 0.01 CI95% [-0,37, 0.35] of proximity on impulsive choice. A Bayes factor of 0.21 gives substantial evidence of no effect of proximity on impulsive choice. We also wanted to use a theory-free metric to ensure the robustness of our findings. Thus, we further tested the effect of near against far with a model-free measure of impulsive discounting behavior, previously described as the area under the curve (AUC) approach (Myerson et al., 2001) (for detailed estimation procedures see supplemental information). We then tested the difference in AUC between the two conditions with a Bayesian paired samples t test, which again yielded a very small effect size (Cohen's *d*) of 0.01 CI95% [-0,46, 0.26] of proximity on impulsive choice. A Bayes factor of 0.28 gave further support for the absence of any difference between conditions. Thus, counter to our hypothesis, these results suggests that, within the domain of impulsive choice, when savings in costs associated with distance are removed, proximity to appetitive cues does not exert a significant impact on impulsive behavior.

DISCUSSION

Here we demonstrate that spatial proximity has a specific impact on impulsive behavior in humans. Using VR, we were able to decouple spatial proximity from associated savings in effort and delay costs, to show that appetitive cues, when they are near, exert a marked effect on the ability of participants to exercise action control. This is consistent with a recent proposal in the field of neuroscience (O'Connor et al., 2014; Westbrook and Frank, 2018) and is analogous with work showing increases in impulsive behavior in rodents when food rewards are near (Morrison and Nicola, 2014). Proximity has also recently been found to play a role in how fearful stimuli are processed, with near threats being more resistant to extinction learning (Faul et al., 2020).

Our study indicates that the impact of proximity to appetitive cues on behavior is observable at the point of impulsive action. In a further experiment we did not observe a comparable effect at the point of impulsive choice. Consistent with a recent theory regarding its influence on dopamine and subsequent action (Mole et al., 2014; Schag et al., 2013a; Velázquez-Sánchez et al., 2014; Westbrook and Frank, 2018), the effect that proximity exerts in impoverishing inhibitory control demonstrates how automatic prepotent actions, those that are evoked by the environment, can interfere with controlled actions, those that are endogenously generated. More specifically, when a No-go stimulus is presented, the process of withholding a response represents a cognitive controlled action which, by providing a greater food reward, affords a more valuable outcome. Yet, for it to occur, rapidly evoked prepotent actions must be overcome. Proximity, as a potent environmental property, may potentiate evoked prepotent actions to the extent that controlled actions are undermined and thus cannot be performed. Since the present experiment was performed by young adult students, future studies would need to test the generalizability of these findings by testing a broader range of ages and education levels.

The absence of any discernible effect of proximity on impulsive choice does not discount the role that it may play in everyday decision making (Baskin et al., 2016; Maas et al., 2012; Musher-Eizenman et al., 2010; Privitera and Zuraikat, 2014; Rozin et al., 2011). To do so would also be to discount the well-established influence that the biases that its associated costs, delay, and effort exert on choice (Aronson, 1961; Croxson et al., 2009; Frederick et al., 2002; Green and Myerson, 2004; Kurniawan, 2011; Prevost et al., 2010). Instead, by controlling for these biases, our observations suggest that proximity, as an active ingredient in itself, does not play a role at the level of impulsive choice.

The finding that humans can be biased by proximity to the extent that a prepotent action can overcome efforts to attain a higher-value alternative appears consistent with the widely held perspective that impulsive behavior is maladaptive. Although this perspective seems intuitive, when viewed more broadly, impulsive behavior only becomes maladaptive when placed in environments in which low-value options are abundant and easy to procure by prepotent actions relative to the existence of greater rewards that may be more difficult to come by through more controlled actions. Such a model certainly applies to modern human society, where M&Ms are easy to attain but the maintenance of physical fitness brought about by healthy lifestyle choices is more difficult. However, it is less applicable to a form of life that exists in impoverished environments in which foraging behavior is the primary means of survival. In this type of environment, one could argue that rapid, immediately rewarding actions are optimal relative to potentially wasteful slower, controlled actions. Under such conditions, the kind of proximity-driven effect on behavior that we observe in the present study is consistent with the argument that impulsive action is adaptive (Stevens and Stephens, 2010).

By carefully controlling for the influence of biases associated with savings in time and effort costs in choosing proximal items, we were able to isolate proximity and demonstrate that its influence goes beyond goal-directed cost estimation (Baskin et al., 2016; Maas et al., 2012; Musher-Eizenman et al., 2010; Privitera and Zuraikat, 2014; Rozin et al., 2011). Instead, we found that the impact of proximity can also be observed at an automatic and uncontrolled stage of behavior. Our observation that individuals, by simply being near to cues representing energy-dense food, find it significantly more difficult to control their actions adds further credibility to the argument that an obesogenic environment plays a toxic role in promoting obesity (Hill et al., 2003; Lake and Townshend, 2016; Swinburn et al., 2011; Walker and Foreyt, 1999). Given the automaticity of this effect, it is debatable as to whether individuals can be considered responsible for their actions in such an environment. Instead, perhaps the burden of responsible decision making should rest on the shoulders of those who regulate the systems within which individuals act (Hollands et al., 2017). This study also serves to highlight how progress in understanding impulsive, and other addiction-related behavior is dependent on the recognition that they arise from a dynamic interaction between the cognitive activity of the individual and its environment (Lewis, 2018).

Limitations of the study

Although we demonstrated an effect of proximity on impulsive action, we were not able to ascertain how this effect scales with value. Future work should include manipulations in the value of No-go stimuli to produce a more detailed picture of this phenomenon. In addition, by using non-appetitive or less appetitive items as Go and No-go stimuli, it would be possible to determine whether the effect of proximity on action is uniquely bound up with appetite or is generalizable to all graspable objects. Another limitation is the absence of complementary working memory tests, which means that assumptions regarding the action of dopamine synthesis in relation to proximity cannot be determined.

Resource availability

Lead contact

Further information and requests for resources should be direct to the lead contact, Jean-Claude Dreher (dreher@isc.cnrs.fr).

Materials availability

Materials in this study are available from the lead contact.

Data and code availability

Original data have been deposited to OSF: https://osf.io/qv8wk/?view_only=8c6e515fd1ff4a7d86cdb2ed16725ce4.

METHODS

All methods can be found in the accompanying Transparent methods supplemental file.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2021.102292.

ACKNOWLEDGMENTS

This work was supported by the European Commission under the MarieSkłodowska-Curie grant agreement (D.A.O'C.: 659680-CL-3DE-H2020-MSCA-IF-2014), IDEXLYON Université de Lyon (project INDEPTH) within the Programme Investissements d'Avenir (J-C.D.: ANR-16-IDEX-0005), Labex CORTEX (J-C.D.: ANR-11-LABX-0042) of Université de Lyon within the Program Investissements d'Avenir (J-C.D.: ANR-16-IDEX-007) operated by the French National Research Agency, the Agence Nationale pour la Recherche (J-C.D.: ANR Social POMDP), and the DFG (J.P.: PE1627/5-1). This work was also supported by grants from the Agence Nationale de la Recherche and NSF in the CRCNS program (J-C.D.: ANR-16-NEUC-0003-01).

AUTHOR CONTRIBUTIONS

D.A.O'C. developed the study concept. D.A.O'C., J.-C.D., R.J., V.G., and J.P. contributed to the study design. D.A.O'C., A.B., and B.T.V. contributed to software development. Testing and data collection were performed by D.A.O'C., R.J., and V.G. Data analyses were performed by D.A.O'C., U.B., U.P., and B.T.V. D.A.O'C. drafted the manuscript under the supervision of J.-C.D., and B.C. provided critical revisions. All authors approved the final version of the manuscript for submission.

DECLARATION OF INTERESTS

The authors declare no competing interests.

Received: September 15, 2020
Revised: January 13, 2021
Accepted: March 5, 2021
Published: April 23, 2021

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iScience, Volume *24*

Supplemental information

Rewards that are near increase impulsive action

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Rewards that are near increase impulsive action

Supplementary Information

Transparent Methods - General

Participants. All participants provided written consent and were reimbursed 20€. Study procedures were approved by the local ethics committee. All participants reported normal or corrected-to-normal vision and did not have a history of psychiatric or neurological disease. All participants had abstained from eating or drinking anything other than water, for at least two hours prior to the arranged testing time and had expressed a liking for chocolate, as indexed by a score of at least four on a five-point Likert scale (0, not at all; 5, a lot). We tested students based in the local area who had responded to a recruitment email sent out to a participant pool. No preliminary analyses were conducted on the data.

Analysis. To compare the effects of near and far conditions on impulsive action we planned to apply Bayesian analyses. Since this method, in contrast to frequentist methods of statistical analysis, provides confidence intervals and Bayes factors, we were able to avoid unfounded confidence in our study outcomes.

Tasks. As any object gets nearer to an observer, the perceived size of the object also increases on the retinae of the observer. This relationship between physical distance and retinal size is a key methodological issue that must be considered during any attempt to investigate the isolated influence of proximity under controlled experimental conditions. Although retinal size may sometimes be suggestive of proximity, it is not indicative of it. Instead it is binocular disparity, the differences in the image of an object provided to each of the retinae, that more readily provides information about an object's distance. Endeavors by the experimenter to completely separate the relationship between proximity and retinal size lead to unnatural viewing experiences such as impossibly large objects in far space and impossibly small object in near space which, although informative in scenarios that utilize abstract objects that have no bearing with the real world (O'Connor, Meade, Carter, Rossiter, & Hester, 2013), only serve to puncture attempts to create a virtually real space with objects that participants can relate to, particularly in terms of their “graspability”. In the current experiments, we implemented a compromise in which the retinal size of the real objects, i.e., the cookie jars, varied naturally as a function of their distance from participants, however, the retinal size of the actual task-related objects, i.e., the shapes on the jars, remained fixed regardless of distance. Such a configuration ensured that the tangibility of real objects was preserved while, at the same time, isolating proximity from retinal size for the abstract objects that participants were ultimately engaging with at the task level.

Both tasks were developed for Oculus VR using Unity software (Unity Technologies, San Francisco, CA) to create a virtually real environment such that participants, who were seated in reality, felt seated at a rectangular table inside a room. The table lent itself to the perception of depth of objects placed upon it, analogous to an ecologically veridical Ponzo-type illusion. The critical near/far manipulation was programmed in such a way that the center of stimulus objects (cookie jars) were 21cm (Near condition) and 360cm (Far condition) from the edge of the table. Upon completion of the task in Experiment 1, participants were asked to estimate the distance from themselves to near and far objects. Average estimations demonstrated that perceived distances were consistent with the aim of presenting objects at near (Mean, 33.76cm; SD, 12.9) and far (Mean, 242cm; SD, 86) distance. Although VR scale was set to 1:1 in Unity software, the difference between programmed and estimated distances in the far location may be attributable to small reductions in scale that are thought to occur in the VR environment.

Methods - Experiment 1: The effect of proximity on impulsive action (3D Go/No-go task)

Participants. Although we set a goal of recruiting 30 participants for each experiment, which we deemed to be an appropriate sample size for the repeated-measures context of the study given the additional power afforded by Bayesian analyses, our stopping rule was primarily based on practical and time constraints. A total of 30 right-handed participants (16, female; mean age = 21.3, SD = 2.42) took part in this experiment.

Go/No-go Task Overview. Participant estimates of distances supported the critical assumption that these objects were perceived as near and, relatively, far. Trials were incentivized with real food rewards to promote the notion that participants, who had previously expressed a strong liking of chocolate through self-report, were viewing appetitive cues. Real jars containing M&Ms resembling the virtual ones were presented to participants prior to testing to reinforce this association. Participants were informed that, at the end of testing, they would receive the average of their winnings from trials randomly selected from each block performed across the task.

Once accommodated to their new VR environment, participants commenced the task. Each trial began by participants binocularly fixating on a cross situated at a distance and visual angle equidistant from subsequent near or far cues. Next, a cue appeared to the left or right from central fixation in the tangible form of a cookie jar on a table. Participants were required to either make (Go) or withhold (No-go) a response depending on which shape (square or hexagon) they saw on the front of the jar on that particular trial. Participants were informed of the shape that corresponded to the No-go trial at the beginning of each short block, this alternated from block to block (of which there were 16). If the shape on the jar represented a Go trial, participants had to rapidly move a virtual hand, using a joystick, in the direction that the jar was located (left or right) and then click a button. If their movement toward the cue was fast enough (based on prior measures of individual response times, see Tasks in Detail section below), participants gained 20 M&Ms. If the shape on the jar represented a No-go trial, participants were required to make no movement whatsoever. Successful withholding of responses led to a gain of a larger number of 100 M&Ms. However, if participants did make a commission error (i.e., an involuntary response), they were rewarded with the same smaller amount of M&Ms that would normally be gained from successful Go trial responding. In this way, we controlled outcomes related to performance within the task so that the value of not responding was always more worthwhile than that gained from responding. Thus, scenarios in which participants make commission errors were analogous to a classical impulsive act whereby a small reward replaces the larger reward that could have been gained from not acting (O'Connor, Rossiter, Yücel, Lubman, & Hester, 2012).

Tasks in Detail

3D practice sessions - Participants completed two short practice sessions in VR. The first session was designed to allow participants to get accustomed to the VR experience and ensure that they were sufficiently comfortable within it. In the same session, they also learned how to perform a standard Go trial. This was managed over stages including first viewing example jars at a fixed middle distance (equidistant to subsequent near and far conditions), moving their virtual hand rapidly from side to side using the joystick, to finally performing example trials. The second session increased in difficulty by allowing participants to perform both Go and No-go trials. Both stages utilized a response threshold for Go trials of 700 ms. Training ceased once both participant and experimenter were satisfied that no additional trials were necessary.

Difficulty calibration task - Given the presence of individual difference in the ability to withhold prepotent actions, we used a task that attempted to calibrate inhibition difficulty across participants in the subsequent Go/No-go task. In this way, we could increase the likelihood of inhibition error commission in the Go/No-go task of participants with greater trait impulsive action control while avoiding the prospect of it becoming too difficult and discouraging for more impulsive participants. The present task, performed on a 2D display using Presentation software (Neurobehavioral Systems Inc, Berkeley, California), applied blocks of 72 trials (Go, 75%; No-go, 25%) in a stepwise manner, aiming to find tailored response thresholds that calibrated No-go error rates to 20% (+/- 5%). Starting at 650 ms, Go trial response thresholds were progressively modulated in each block by 50 ms until participants' proportion No-go errors rates reached 20% (+/- 5%). Blocks did not go beyond two steps (+/- 100 ms from 650 ms) before error rates were calibrated, however, if modulations of 50 ms induced too great a change in performance, thresholds were adjusted by 25 ms accordingly (e.g., 575 ms).

3D Go/No-go task – The task consisted of sixteen short Go/No-go blocks, each containing 14 trials. Each of these blocks was preceded by a shorter block containing eight Go-control trials. All trials were split equiprobably between both Near and Far conditions. Across the whole task, this design gave a total of 32 No-go trials for each distance condition. These were presented among 80 Go trials per distance condition, giving a Go to No-go ratio of 2.5:1. The total number of Go-control trials across the whole task was 64 for each distance condition with both shapes presented in equal proportion.

In each trial, participants were presented with a cookie jar bearing one of two possible shapes, namely a square or a hexagon. For Go/No-go trials, participants had to respond as quickly as possible when presented with one shape (Go stimulus) but refrain from responding when presented with the other shape (No-go stimulus). Shape-response contingencies (respond or inhibit) alternated across experimental Go/No-go blocks. We informed participants prior to the task that, for every successful response to a Go stimulus, they could win 20 M&Ms, while, for every withheld response for a No-go stimulus, they could win 100 M&Ms. Insufficiently rapid responses for Go stimuli resulted in no reward, whereas failures to refrain from responding in the presence of No-go stimuli were rewarded with 20 M&Ms. In this way, unsuccessful inhibitions of response were intentionally treated in the same manner as successful responses to Go trials. This reward contingency can be likened to a scenario whereby a motor action leading to the attainment of a small reward also leads to the simultaneous foregoing of a greater reward.

For Go-control trials, participants were required to respond as fast as possible for every cookie jar that was presented, regardless of shape. Participants received reward feedback if their responses were sufficiently rapid (as determined by the difficulty calibration task). Non-responses or response times above each individual's threshold were not rewarded. In addition to providing an index of non-inhibited action, Go-control trials also served to recalibrate response associations with shapes from preceding blocks. In this way, participants could begin each Go/No-go block having just associated both shapes with rewards derived from rapid non-inhibited responses.

Procedure. Participants were first presented with real cookie jars that resembled those employed in the subsequent VR environment and contained amounts of M&Ms (20 and 100) corresponding to those that would be used in the experiment. At this point, they were given a brief explanation of what they were required to do and were able to experience (view, handle, smell) jars containing the quantities that they would be dealing with in the task. They were informed that, given that the final amount of M&Ms that they would be rewarded would be an average of randomly selected trials from each block of the 3D Go/No-go task, it was important to perform consistently well in order to optimize winnings.

Once participants had completed a short phase of instruction explaining Go trials, they then performed the first 3D practice session (see above). Following another session of instruction introducing the component of No-go trials, participants performed the second 3D practice session (see above). Participants then performed a difficulty calibration task (see above) and the result of this was used to set the response threshold for the subsequent 3D Go/No-go task (see above).

Participants then performed the sixteen short blocks of the 3D task and were permitted breaks after every second block. For each trial, participants viewed a fixation cross that was situated at a location and viewing angle that was equidistant from both prospective near and far objects. This prestimulus was pseudorandomly jittered and had an average duration of 2s (ranging from 1.5 to 2.5 s).

At the beginning of Go-control phases, participants were asked to respond as fast as possible for every cookie jar that was presented, regardless of shape. Whereas, at the beginning of each Go/No-go block, participants were presented with the 3D No-go stimulus and informed “From now on, by not responding to this jar, you will get 5x its value (100 M&Ms)”. Using a joystick, participants made responses by moving a virtual hand to the left or right consistent with the lateral location of stimulus. Upon reaching the jar, the hand stopped and participants were required to click a button on the joystick to obtain the jar. The duration of stimuli presentation was determined by participants’ performance in the difficulty calibration task (range, 575-750 ms) and was followed by feedback consistent with performance in the trial. Specifically, in both Go and Go-control trials, a sufficiently rapid response resulted in the presentation of red circle surrounding the cookie jar to indicate that it had been attained (20 M&Ms), whereas responses above the specified threshold resulted in a message reading “too slow”. The intentional absence of feedback, associated with successful response withholding of No-go stimuli, is analogous to real scenarios in which an agent’s non-action, by abstaining from an easily accessible and available reward in exchange for a greater alternative, shows no immediate effect in its proximate environment. Once all blocks of the experiment were completed, both near and far objects were presented again to participants and they were asked to estimate, in centimeters, how far away the objects were.

Methods - Experiment 2: The effect of proximity on impulsive choice (3D intertemporal choice task)

Participants. A total of 26 right-handed participants (15, female; mean age = 22.1, SD = 3.16) took part in this experiment. One participant was excluded because modelling of their choices from the "2D indifference points tasks" (see below) were not able to produce functional outcomes for the subsequent "3D intertemporal choice task". In addition, three participants did not attend their research sessions. To compare the effects of near and far conditions on impulsive choice we planned to apply Bayesian analyses. Since this method, in contrast to frequentist methods of statistical analysis, provides credible intervals and Bayes factors we were able to avoid unfounded confidence in our study outcomes. Although we set a goal of recruiting 30 participants, which we deemed to be an appropriate sample size for the repeated-measures context of the study given the additional power afforded by Bayesian analyses, our stopping rule was primarily based on practical and time constraints. In this instance, because one participant was excluded due to issues with performance and three participants did not attend, we ultimately tested right-handed 26 participants (n = 26). No preliminary analyses were conducted on the data.

3D Intertemporal Choice Task Overview

Once accommodated to their new VR environment, participants started the task. Each trial began with them binocularly fixating on a cross situated at a distance and visual angle equidistant from subsequent possible near or far cues (Fig. 2a). Next, participants were presented with a choice between two different amounts of M&Ms. The larger-later option, which could only be obtained at a specified point in the future, was presented in written form at the top of the screen (e.g., 244 M&Ms in 12 days). The lesser but more immediate (smaller-sooner) alternative was presented in the form of a cookie jar bearing one of four possible shapes. We presented smaller-sooner and larger-later options in two distinct ways for the following reason. In the context of an intertemporal choice task, an impulsive choice is always manifested as the choosing of the smaller-sooner option. For this reason, it was important that the stimulus associated with the impulsive option should take the form of an actual "concrete" object that was related to food and uncomplicated in form. Larger-later options, on the other hand, were not presented in any concrete form since they are, by definition, not immediately attainable. For this reason, larger-later options were presented in word form, which can be considered a less concrete, more abstract representation of an option.

Prior to the experiment, participants had been trained to associate shapes with small quantities of M&Ms and were shown equivalent jars in the real world with their corresponding amounts inside. Thus, in the experiment, these shapes indicated to participants how many M&Ms were "inside" jars (M&Ms ranged from 60, 80 to 100, plus a catch trial, see Tasks in Details section below). These were situated in a right or left lateralized location which, crucially, were located either within reach (near) of participants or further down the table (far).

After both larger-later and smaller-sooner options had been presented to participants, they were then required to make a choice. They did this by using a joystick to move a virtual hand to the left or right depending on the lateral location of the jar. A move towards its lateral location indicated a choice for the smaller-sooner offer, whereas a move towards the opposite location indicated a choice for the larger-later option. Such a configuration allowed us to isolate proximity as an experimental variable by controlling two irrelevant factors, namely effort and time. Firstly, along the *x* axis of movement (lateral) and at the within-trial level, time and effort were equivalent regardless of whether participants chose the smaller-sooner option or the larger-later option. That is, movements (either to the left or right) and button clicks were the same regardless of choice, thus removing the potential for biases which were not driven by proximity. Secondly, along the *z* axis of movement (from near to far) and at the between-trial level, time and effort were equivalent regardless of whether the smaller-sooner items that participants chose were near or far. That is, choices relating to cues that were distant did not incur the usual costs with which they are normally associated, whereby an individual would have to spend time and effort travelling towards them. Instead, participants always made lateral movements to indicate their choices regardless of distance.

We informed participants that one of their choices would be randomly selected to form the reward that they would ultimately receive after performing the task. If the randomly selected trial was a smaller-sooner choice, they were free to eat the specified number of M&Ms immediately. To enhance the authenticity of contingencies related to delayed reward outcomes, we instructed participants that M&Ms gained from a trial in which they chose a larger-later option would only be available after the specific delay had elapsed. Thus, food rewards requiring a wait were given to participants inside a small glass jar securely locked with a small padlock that could only be opened with a secret three-digit number. Once the waiting time had fully elapsed, for example after 12 days, participants would receive an SMS that included the number allowing them to access their reward. Although the monetary value of the jar and padlock was not high, we controlled for the possibility that participants might be encouraged to choose larger-later options in order to acquire these items by making them available, regardless of final reward outcome, to any participants who might want them.

Tasks in Detail

Multi-shape training task - Prior to the 2D and 3D intertemporal choice tasks, participants performed a short two-stage computerized training task on a 2D display, using Presentation software (Neurobehavioral Systems Inc, Berkeley, California) which reinforced associations between the shapes on the front of cookie jars and amounts of M&Ms. The first stage was passive whereby participants viewed explicit presentations between each shape and its corresponding amounts. Presentations were repeated five times for each shape. The second stage was active and involved trials in which one of the five shapes were presented and participants were required to select the correct amount from five possible options. Participants could not progress to the next trial until they had correctly matched the shape with the correct amount. Moreover, participants could not complete the active stage of the task until they had completed two cycles without making an error (one cycle comprised of three presentations of each shape). This process ensured that participants held strong shape-amount associations, thus enabling them to rapidly infer how many M&Ms were inside a given jar on each trial.

3D practice sessions - Participants also completed two short practice sessions in VR. The first session was designed to allow participants to get accustomed to the VR experience and ensure that they were sufficiently comfortable within it. In the same session, they also learned how to perform a standard trial. This was managed over stages including first viewing example jars at a fixed middle distance (equidistant to subsequent near and far conditions), moving their virtual hand rapidly from side to side using the joystick, reading delayed amount information, to finally performing example trials. The second session increased in complexity by allowing participants to perform practice trials employing each of the five shapes that they had learned during the training task, also serving to further reinforce shape-amount associations. This session also allowed participants to view jars at both near and far distance and to practice trials that utilized these distance manipulations.

2D indifference points task - Prior to taking part in the 3D choice task, participants performed a brief intertemporal choice task, using Presentation software (Neurobehavioral Systems Inc, Berkeley, California) on a standard flat screen monitor. With the exception of depth, this 2D version featured the same key characteristics as those employed in the 3D version. Specifically, on each trial, participants first viewed a central image of a virtual hand at the bottom of the screen. Next, a larger-later reward option was presented in the top section of the screen (e.g., "107 M&Ms in 7 hours") and an image of a cookie jar bearing a shape representing the smaller-sooner amount that was on offer (for the 2D task this was fixed at 80 M&Ms, square shape) was presented midway along the horizontal plane to the left or right. Once the larger-later reward option left the screen (after 3 s), participants were required to indicate their choice by making a rapid response (within 1s). For smaller-sooner choices, participants were required to move their hand in the direction of the jar, whereas a choice for later-larger amounts required a movement in the opposite direction. A stepwise algorithm was employed (varying larger-later reward between 82-360 M&Ms) enabling estimation of each participant's indifference points at eight delay levels (5 mins to 14 days), overarching those that would be available in the subsequent 3D task. A hyperbolic discount function (with parameter *k*) was fitted to each participant's delay and indifference point data using Maximum Likelihood Estimation in Matlab (The Mathworks, Natick, MA). This estimated hyperbolic *k* parameter was then used to calculate predicted indifference points to generate stimuli in the subsequent 3D task.

3D intertemporal choice task - In each trial, a cookie jar was presented bearing one of four possible shapes. Each shape corresponded to a different amount of M&Ms that could be consumed almost immediately after the experiment. Given the importance of the near/far manipulation, we hoped that, by varying amounts and shapes, we could maintain engagement between participants and these stimuli. In addition to offers of 80 M&Ms (square), there was an equal probability that amounts 25% lower (60 M&Ms, triangle) or higher (100 M&Ms, hexagon) than that sum could also be offered. We also presented catch trials, taking the form of a jar bearing a star, which were presented intermittently throughout the task. Given that selection of this jar signified that the larger-later amount could be consumed immediately rather than having to wait, we could assume that instances of its non-selection indicated non-engagement with these stimuli. Thus, participants that did not choose jars in catch-trials were excluded from further analysis.

The task consisted of four blocks each containing 56 trials, two of which were catch trials (one near; one far) leaving 54 real trials (27 near; 27 far). Across the whole task this gave 108 trials for each distance conditions (18 for each of the six delays). This was further broken down into 54 linear spaced delay/reward offers for each distance (for each of the six delays, offer amounts were equally distributed ranging from lowest to highest) and 54 delay/reward offers tailored to each participant (for each of the six delays, offer amounts were concentrated around points of indifference as determined by the 2D task). In addition, two thirds of amounts for each delay were adjusted by 25% (+/-) to correspond with the same adjustments in smaller-sooner amounts presented on jars, thus ensuring that differences for smaller-sooner amounts relative to larger-later amounts remained the same. Furthermore, a small jitter (+/- 1) in amounts ensured that participants were not presented with duplicated offers across any conditions. Larger-later amounts ranged from a minimum of 61 M&Ms to a maximum of 444 M&Ms (accounting for +/- 25% and +/- 1 adjustments of base amounts of 82 M&Ms and 354 M&Ms) that were offered across six delays (10 minutes; 2 hours; 7 hours; 2 days; 6 days; 12 days).

Computational modeling – we approximated the devaluation of value over time by fitting a hyperbolic model (Mazur, 1987) to the choice behavior from the 3D choice task, in the form of:

$$SV = R / (1 + k * D)$$

where SV = subjective value, R = reward; D = delay in hours; k = discount rate. Maximum likelihood parameter estimation was done using optimization procedures that are implemented in Matlab, Version R2014 (Mathworks, Natic, MA, fminsearch) using a softmax action selection function in the form of:

$$P_{chosen} = (\exp(SV_{chosen} / temp) / (\exp(SV_{chosen} / temp) + \exp(SV_{other} / temp)))$$

where P_{chosen} = the probability of the chosen option; SV_{chosen} = subjective value of the chosen option; SV_{other} = subjective value of the other option; *temp* = temperature. In order to test our hypothesis, the model was fit to all trials from each participant, separately for each condition. In this way the discount rate (k) which is considered an index of impulsive behavior, was obtained individually for each participant. The estimated individual parameter *temp,* which is an indication of the noise in the choice data, was not analyzed any further. Since the task encompassed three sizes of smaller-but-sooner values, we tested whether the data was better fit by one single parameter across all smaller-but-sooner values or by separate parameters per smaller-but-sooner values. Across all participants the BIC goodness-of-fit proved the fit of one parameter across all smaller-but-sooner values to be superior (Table. S1). To account for skewed distributions of the estimated parameter *k*-values, we chose a non-parametric square-root transformation, due to exceptionally noisy choice behavior from three participants.

For the model-free analysis, we estimated indifference-points (ID-points) for each participant by fitting a logistic curve to the proportion of choices of the larger-later reward as a function of the larger-later amount, per delay, per size of smaller-sooner amount and per condition (Bromberg, Lobatcheva, & Peters, 2017). Likewise, based on those ID-points, we then calculated the AUC for each participant. Finally, the individual AUC's were averaged across all sizes for a comparison of the two main conditions of interest. For visualization of the AUC-Group effect, ID-points were limited to a maximal value of 1 and averaged across all participants (see Fig. S1)

Procedure. Participants were first presented with a real cookie jar, resembling those employed in the subsequent VR environment, bearing a square shape and containing 80 M&Ms. At this point, they were given a brief explanation of what they were required to do in the experiment and were able to experience (view, handle, smell) a jar that contained 80 M&Ms. They were also presented with a small glass jar locked with a small padlock and its purpose was briefly explained. Specifically, if a larger-later option was randomly selected from their array of choices made during the 3D experiment, they would receive the locked glass jar containing the amount corresponding to their choice which could only be opened with a secret 3-digit combination. Participants would only be able to access the M&Ms in the jar once the specific delay corresponding to their choice had elapsed, at which point they would receive a 3-digit combination by SMS that could be used to unlock the padlock.

Once participants had completed a short phase of instruction, they then performed the first 3D practice session (see above). Next participants, performed the 2D task (see above) designed to derive indifference points unique to each participant which would be used to generate stimuli for the 3D task. Once the 2D task was completed, participants read instructions introducing them to the additional cookie jars. They were also given the opportunity to experience (view, handle, smell) real versions of these additional jars and their contents. Then, while the experimenter calculated indifference points and generated 3D task stimuli, participants performed the multi-shape training task (see above). Once completed, participants then had the opportunity to perform trials with the new stimuli during the second of the short 3D practice sessions (see above). By this point, participants were familiar with and well-prepared for the task but, importantly, were not aware of the relevance of the distance manipulation.

Participants then performed the four blocks of the 3D task (see above) and were permitted breaks in between each. For each trial, participants viewed a fixation cross (duration, 1 s) situated at a location and viewing angle that was equidistant from both prospective near and far objects. Participants then viewed offers for both larger-later (in written form) and smaller-sooner (in shape form) options. Once the larger-later option left the screen (3 s), participants were required to make a choice as quickly as possible. Choices were indicated by moving a virtual hand, using a joystick, to the left or right. A movement toward the lateral position of the jar indicated a preference for the smaller-sooner options, whereas a movement toward the opposite lateral position indicated a preference for the larger-later option. Upon reaching the jar (or a location equidistant from starting point in the opposite direction), the hand stopped and participants were required to click a button on the joystick to register their choice. If participants clicked to choose the smaller-sooner option, their decision was registered with a red ring showing that they had attained the contents of the jar. A move and click in the opposite direction to choose the larger-later option was not registered with any similar feedback. Similar to Experiment 1, the intentional absence of feedback, this time associated with choosing a larger-later option, is analogous to real scenarios in which an agent's decision to abstain from an immediate reward in exchange for a greater but delayed alternative, shows no immediate effect in its proximate environment. If participants were not able to register their choice within 1 second, they were provided with written feedback ("too slow"), indicating that they would not receive any M&Ms if this particular trial was selected post-experiment.

Results - Experiment 1: The effect of proximity on impulsive action (3D Go/No-go task)

Additional results. Given that the majority of the task consisted of responding to Go trials, could the finding of proximity-related increases for errors on near No-go trials be simply explained by the faster responses to corresponding near Go trials? Although the possibility of such a trade-off between speed and accuracy is highly probable within such a paradigm, we wanted to determine whether any effect of proximity would remain after considering its influence, To do this, based on a previously established frequentist analysis (Seli, Jonker, Cheyne, & Smilek, 2013), we reanalyzed the variances between near and far No-go errors while including response times (RTs) across the two conditions as a covariate. After dissociating No-go errors from RTs in this way, we were still able to observe a significant increase in No-go errors when cues were near compared to when they were far ($F(1,58) = 11.81$, $P = <.001$, $\eta_p^2 = .172$, analysis of covariance). Such independence supports the notion that observed impoverishments in the ability of participants to withhold responses over near cues cannot be explained by factors other than impulsivity, such as vigilance or decision speed (Seli et al., 2013).

Analogous frequentist statistics. Near vs. Far, errors of commission (no-go errors) - In line with our hypothesis, we found that participants made significantly more commission errors when they were required to withhold responses for No-go cues that were near (42.71%)

compared to when the same types of cues were far (25.73%) ($t29$ = 6.926, p = <.001, d = 1.26 paired t-test).

Near vs. Far, errors of omission - We observed a numerical difference which did not reach the level of statistical significance (near, 32.38% vs. far, 35.79%; $t29$ = 1.835, p = .077, d = 0.33 paired t-test), suggesting that attention/vigilance may have played some role during task performance.

Near vs. Far, Go-control trial RT - Here we observed a reduction in the latency of actions when cues representing Go-Control trials were near (340.9 *ms*) compared to when they were far (378.9 *ms*) ($t29$ = 13.146, p = <.001, d = 2.4 paired t-test).

Go-control trial RT vs Go trial RT - We observed a significant slowing for Go trials as participants adjusted their speeds to allow for the prospect of response inhibition (Go-Control, 359.9 *ms* vs. Go, 445.6 *ms*; $t59$ = 19.97, p = <.001, d = 2.58 paired t-test).

Near vs. Far Go trial RT - When comparing near and far Go trials, although less pronounced than the differences produced by Go-Control trials, we also observed a reduction in the latency of actions for Go trials that were near (439.4 *ms*) compared to far (451.8 *ms*) ($t29$ = 3.079, p = .005, d = .56 paired t-test).

Results - Experiment 2: The effect of proximity on impulsive choice (3D intertemporal choice task)

Analogous frequentist statistics. With human discounting behavior being reasonably well characterized by a hyperbolic function (Green, Myerson, & Macaux, 2005), we used the hyperbolic model (Mazur, 1987) to obtain individual estimates of discounting rates (parameter k) for both near and far conditions, as a measure of impulsive choice. Across participants t-test comparisons revealed that there were no statistically significant differences in impulsive behavior between the near (k(sqrt) = -2.218) and far (k(sqrt) = -3.390) distance manipulations (Fig. 2b; U = 274, p = .551, Mann-Whitney test). Counter to our hypothesis, this result suggests that, within the domain of impulsive choice, when savings in costs associated with distance are removed, proximity to appetitive cues does not exert a significant impact on impulsive behavior.

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Parameter	Summed Scores
Ik/1temp	4690.21
1k/3temp	5042.68
3k/1temp	5098.76
3k/3temp	5462.95

Table S1 | BIC goodness-of-fit scores for hyperbolic model-fits: 1 k- and 1 temp-parameter across all smaller-but-sooner values (1k/1temp); 1 k-parameter across all smaller-but-sooner values and 3 temp-parameters individually for each smaller-but-sooner value (1k/3temp); 3 k-parameters individually for each smaller-but-sooner value and 1 temp-parameter across all smaller-but-sooner values (3k/1temp); 3 k- and temp-parameters individually for each smaller-but-sooner value (3k/3temp). Note that a smaller value indicates a better fit. Relate to Figure 4.

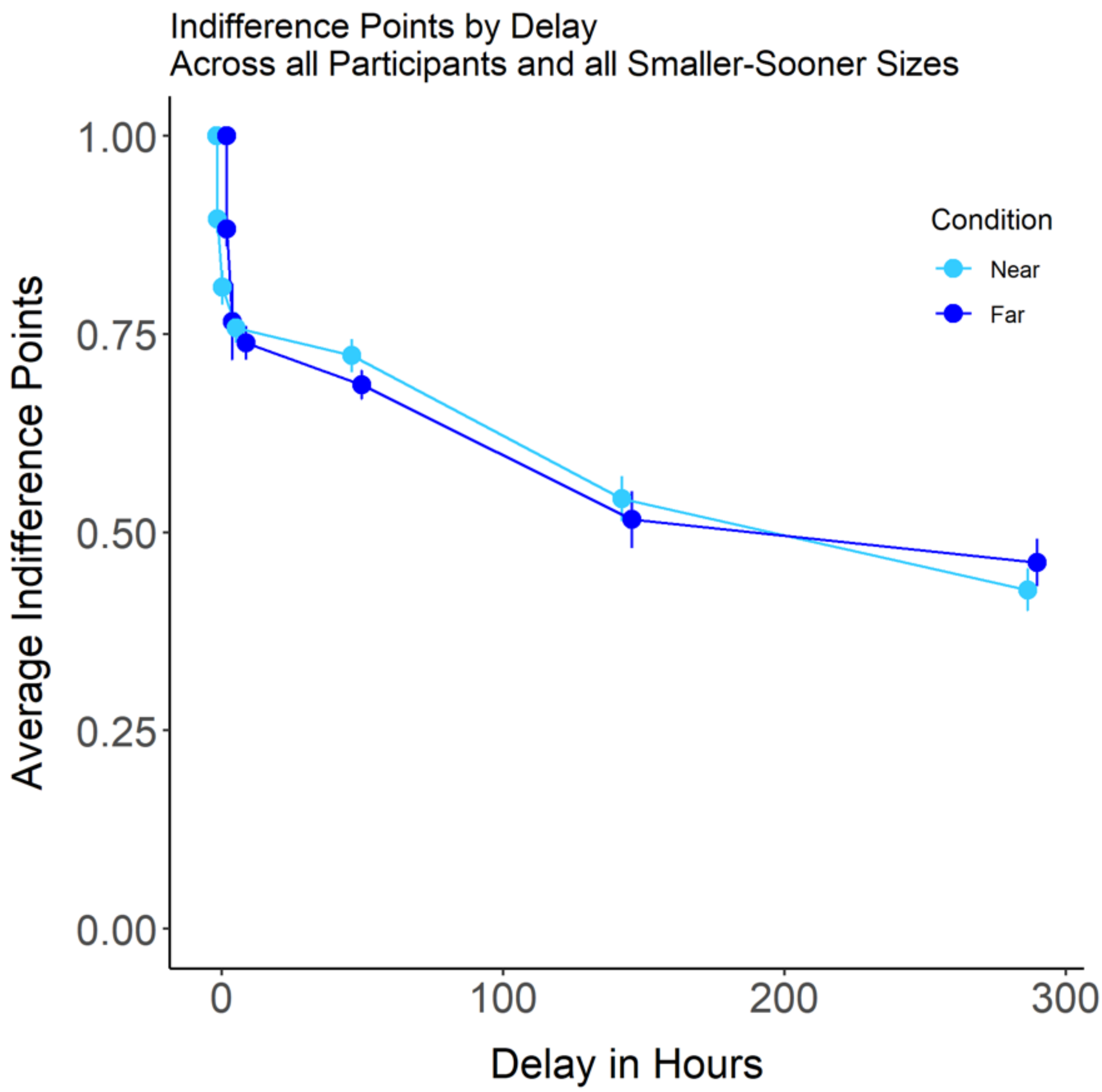

Figure S1 | AUC model-free analysis: Indifference points by delay across all participants and all SS values. Related to Figure 4.