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# Health factors that influence sustainable behaviour in a single-player resource management game

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**Abstract**

Encouraging sustainable use of limited natural, social, and economic resources requires understanding the variety of ways in which people think about how resources work and how they adjust their behaviour (or not) as available resources fluctuate. Previous investigations which have focused on understanding how individuals navigate erodible resources, have tended to use group-based, common pool games. However, such social games make it difficult to disentangle whether resource erosion is linked to difficulty navigating the dynamics of the resource or caused by social factors. Here, in two experiments, we recruited 781 participants to play a single-player resource management game in which individuals were invited to harvest monetary rewards from a fully depletable but stochastically replenishing resource over time. We find that the ability to sustain a resource over successive harvesting opportunities (in order to maximise the total harvested rewards) is reliably worse in individuals reporting elevated psychological distress, the often co-occurring hazardous alcohol use, and elevated rates of delay discounting. The associations between resource outcomes, harmful alcohol use, and psychological distress remained substantial even once we had controlled for elevated discounting rates (as a form of impulsivity and a strong risk factor for these health challenges). By contrast, individuals who reported higher levels of financial literacy and general well-being achieved better resource outcomes. Our observations demonstrate that the capacity to respond effectively to the dynamics of a resource are compromised in individuals at risk of psychological and alcohol-related disorders.

## Introduction

Identifying sustainable ways to use valuable but erodible resources is now an economic, environmental and public health imperative for individuals, communities and governments (Armstrong & Kamieniecki, 2019; Kanger et al., 2020; Macke & Genari, 2019). Characterising the variation in behaviour and outcomes of behavioural economic 'take-some' common-pool games (Balliet et al., 2009; Brewer & Kramer, 1986) can help us to understand the different ways in which individuals engage with dynamic but depletable resources and contribute to the development of effective interventions and policy across communities.

Surveying the literature, an extensive evidence-base indicates that behaviour and resource failures in common-pool games can involve the cumulative impacts of individuals' attitudes, cognitions, affect, and behavioural biases (Van Lange et al., 2013). Careful harvesting behaviours can reflect individuals' pro-social attitudes (Balliet et al., 2009; Bogaert et al., 2008; Kramer et al., 1986), environmental attitudes (Sussman et al., 2016), emotional reactivity to environmental concerns (Tarditi et al., 2018), intrinsic values and motivations (Han et al., 2018), and risk-aversion (Chermak & Krause, 2002). More broadly, there are mixed findings of differing harvesting behaviours in males compared with females, but more consistent evidence of smaller harvests (in order to sustain resources) in older compared with younger individuals (Chermak & Krause, 2002; Tisserand et al., 2022). Lastly, groups consisting of higher average cognitive ability (as 'Spearman's g') and stronger appreciation of other peoples' mental states (as 'Theory of Mind') tend to sustain resources for longer and (in the former case) maximise totals harvested (Freeman et al., 2020).

While these experiments suggest that sustainable behaviour and outcomes of common-pool games are moderated by individual characteristics, interpreting their findings is challenging.

Behaviour in common-pool games reflects the integration of at least two sets of socio-cognitive processes: (i) individuals' understanding and responses to the social aspects of managing a resource in a group (e.g. attributions of partners' motivations, affective reactions to partner behaviours, and predicted harvests) and (ii) learning about the dynamics of a resource itself and the other externalities that contribute to its fluctuating value against harvesting demands. Of course, these processes are not independent but inter-relate in complex ways; for example, subtle and diffuse social framing effects operate across single-player games and both formal experimental and commercial game settings (Bernold et al., 2015; Ellingsen et al., 2012; Stenros et al., 2009).

Nonetheless, navigating the dynamics of the resource is also non-trivial. Even in common-pool games, individuals often need to diagnose the properties of the resource over time (e.g. they are often not given the replenishment rate of the resource and must estimate this through trial and error). So, behaviour may be conditioned by an individual's understanding of the resource, their estimate of the likely resource replenishment rate, or how steeply they discount the value of future benefits afforded by a still-viable resource (Hendrickx et al., 2001). Thus, investigations with single-player games offer opportunities to observe how individual characteristics moderate responses to resource dynamics, while removing the most overt social challenges inherent in multi-player games.

A relatively small number of studies have removed the social aspects of common pool games and tested whether individuals struggle to navigate resource dynamics in isolation. The outcomes in single-player resource games, like those of common-pool games, tend to be heterogenous (Hey et al., 2009; Messick & McClelland, 1983; Schnier & Anderson, 2006). Operating by themselves, some struggle to sustain resources, eroding or exhausting them

prematurely. This is true even for individuals with expertise in resource dynamics, such as experienced fishers and policy makers (Moxnes, 1998, 2000). It is also the case irrespective of whether resources are framed as natural in kind, such as fish stocks (Brechner, 1977; Knapp & Clark, 1991; Moxnes, 1998; Tice et al., 2001) and grazing land (Moxnes, 2000, 2004) or as abstract pools of nominal rewards (Messick & McClelland, 1983). Individuals can also struggle to sustain resources when replenishment rates reflect biologically-informed contingencies (Moxnes, 1998, 2000) or simpler stochastic percentages (Knapp & Clark, 1991; Messick & McClelland, 1983; Moxnes, 2004). Further, single-player resource management outcomes are varied in both children (Koomen & Herrmann, 2018a) and chimpanzees (Koomen & Herrmann, 2018b) – although children and chimpanzees perform better in isolation compared to group-based settings.

Despite the fact that some individuals struggle to navigate resource dynamics in a single-player game, there is little work which has tried to understand the individual characteristics associated with (un)sustainable behaviour in a single-player setting. However, we believe that improving our understanding of the individual characteristics associated with outcomes in single-player resource games is an important precursor to understanding the difficulties faced when individuals are placed in more complex, social resource management contexts, such as common pool games. As noted above, since common pool settings have inter-related underlying socio-cognitive processes, using single-player games can help us better isolate and investigate how individuals navigate resource dynamics. Future work on group-based resource maintenance can then amalgamate the causes underlying variation in individual resource management behaviours with the social dynamics of multi-partner interactions.

In these experiments, we begin the process of investigating how individual characteristics relate to resource outcomes in a single-player game. Specifically, we evaluate whether adverse health experiences and their risk factors are associated with resource outcomes. We test whether resource outcomes vary by validated measures of psychological distress (as depressive and somatic symptoms; Goldberg et al., 1997), hazardous alcohol use (Reinert & Allen, 2002; Saunders, Aasland, Amundsen, et al., 1993), and delay discounting (Koffarnus & Bickel, 2014).

There are three reasons why we expect poor sustainable behaviour to be linked to psychological distress, harmful alcohol use, and delay discounting rates. First, at an observational level, social and economic hardships are associated with high rates of depression, anxiety, and alcohol misuse (Adda et al., 2009; Bellis et al., 2016; Marmot, 1999) as well as other risky, unhealthy behaviours (Haushofer & Fehr, 2014; Huckle et al., 2010; Makela, 1999; Sze et al., 2017). In turn, the impacts of these experiences – for example, prolonged stress – can undermine the effective use of financial, social and clinical resources necessary for the development of resilience and/or protection against relapse (Adinoff et al., 2016; Haushofer & Fehr, 2014; Richardson et al., 2017). Thus, we hypothesize that the resource outcomes of affected individuals playing a single-player game will mirror their lived experiences of resource management and be demonstrably poorer as a function of self-reported depressive symptoms and hazardous alcohol use.

Alongside this, a large evidence-base indicates that depression, anxiety, and alcohol misuse are associated with difficulties in reward-based ('reinforcement') learning and decision-making under conditions of uncertainty (Bishop & Gagne, 2018; Gray & MacKillop, 2015; Hagiwara et al., 2022). This suggests that resource management in single-player games,

mediated by these same cognitive functions, will be altered in individuals reporting these heath challenges. So far as we are aware, however, the only relevant evidence in the context of single-player games are two demonstrations of poor resource outcomes following transient reductions in mood in samples of broadly healthy adults (Knapp & Clark, 1991; Tice et al., 2001). At the current time, there are no published tests of how the resource outcomes in single-player games vary by validated measures of self-reported psychological distress, alcohol use or well-being. Here, we test these associations directly.

Finally, at a theoretical level, other data demonstrate that behavioural responses to social dilemmas – for example, in common-pool games – can reflect 'temporal traps' where individuals may struggle to consider the importance of preserving resources for the longer term (Mannix, 1991). More broadly, however, steeper delay discounting rates (as individuals' tendency to devalue rewards over increasing time intervals to their delivery: Ainslie, 1975; Odum, 2011; Petry, 2001; Story et al., 2014) can be associated with diminished appraisals of the seriousness of human-instigated environmental change (Farias et al., 2021) and fewer self-reported pro-environmental behaviours (Sahraeian et al., 2021). As such, variability of delay discounting is a central aspect of how we measure and understand poor resource management behaviour (Hirsh et al., 2015).

Convergently, steeper discounting rates are also a well-attested risk factor for a number of psychological disorders linked to problematic patterns of consumption, including alcohol use disorders (Case et al., 2019) and co-occurring: depression, somatic symptoms, and social withdrawal (Åhlin et al., 2015; Fields et al., 2014; Levitt et al., 2023). So, good resource outcomes in single-player games are likely to reflect individuals' tolerance of delays to the larger rewards (offered by sustained resources) while poor outcomes are likely to reflect, at

least sometimes, early aggressive harvesting mediated by higher rather than lower delay discounting rates (Odum, 2011; Petry, 2001; Story et al., 2014). Thus, examining the variability in the resource outcomes of individuals reporting harmful alcohol use, stress, and depression may offer a fresh perspective on how elevated delay discounting (which is associated with changes in other cognitive and affective processes) operate to promote maladaptive resource management behaviour in vulnerable populations. Our experiments offer the first test of these possibilities.

Here, in two separate experiments, we sought to characterise the varying behaviours and outcomes of a single-player resource management game in which individuals were invited to harvest monetary rewards from a fully depletable but replenishing resource over time. Overharvesting behaviours tended to diminish the resource, limiting future opportunities to gather rewards; while more moderate harvesting sustained the resource, preserving opportunities to gather more rewards for longer (Messick & McClelland, 1983). In Experiment 1 (N = 400), we tested the hypothesis that resource outcomes are poorer for individuals reporting higher levels of psychological distress (and accompanying somatic symptoms), higher delay discounting, lower well-being, and stronger patterns of hazardous drinking. We also sought to identify other factors that might *improve* the management of resources and so we tested whether resource outcomes are positively associated with the life-skill of financial literacy. In Experiment 2 (N=381), we sought to replicate part of Experiment 1, and tested whether high delay discounting and strong patterns of alcohol use were associated with poor resource outcomes.

## Experiment 1

We sought to better understand the relationship between the resource outcomes in a single-player resource management game and (i) psychological distress – using the 12-item General Health Questionnaire (GHQ-12: Goldberg et al., 1997; Hankins, 2008); (ii) hazardous alcohol use – measured by the 10-item Alcohol Use Disorders Identification Test (AUDIT: Saunders, Aasland, Amundsen, et al., 1993); (iii) delay discounting rates – using the 5-item $ED_{50}$ elicitation (Koffarnus & Bickel, 2014); (iv) financial literacy – using 9 Organisation for Economic Co-operation and Development (OECD) survey items (Čonková, 2014) and; (v) general well-being – measured by the 5-item World Health Organisation (WHO-5) scale (Topp et al., 2015).

### Method

#### *Participants*

Ethical approval for the protocol was given by the Bangor University School of Psychology Research Ethics Committee. Four-hundred participants took part, recruited from the online participant pool, Amazon Mechanical Turk (MTurk: http://mturk.com). The sample consisted of 178 females, 221 males, and 1 non-binary with a mean age of 34.4±10.2 (SD). The survey questions were hosted on the Qualtrics platform and participants completed the survey through their web-browser. The experiment was only made available to MTurk workers based in the United States of America with at least a 95% approval rating from previous studies. No participant was excluded.

Participants were told they would earn a minimum base pay of $1.50 for completing a 15-20 minute online survey, with a chance to earn a bonus payment of up to a value of $3, based on how well they performed in a resource game. Potential payments of $13/hour is generous compared to the average MTurk compensation (Hara et al., 2018), so we believed this would provide sufficient motivation. Of note, after the experiment, we calculated that participants earned an average bonus of $0.87±$.61(SD), on top of their base pay (bonus payments ranged from $0.30 - $2.47). Using the time it took for each participant to complete the protocol, the average rate of pay was $8.00±$3.42 per hour.

***Materials***

*Resource Management Game:*

At the beginning of the protocol, participants played the resource management game. When the game began, participants saw a pool or 'resource' of 60 rewards – its maximum value – and were told they could earn bonus money based on the number of rewards they harvested. This bonus was capped at $3, and participants were not told the value of each harvested reward ($0.005) until after the game finished. Each harvesting opportunity, or 'round', was broken into three phases (see Figure 1). First, participants selected how many rewards they wished to harvest from the resource. They could harvest any amount. Second, the value of the harvest was subtracted from the resource and added to the participant's (unseen) total accumulated rewards. Finally, the remaining pool was replenished by a hidden replenishment function.

Behavioural models of resource management have tended to use one of two replenishment functions: (i) Gaussian (bell-shaped) functions where the optimal behaviour is to harvest half

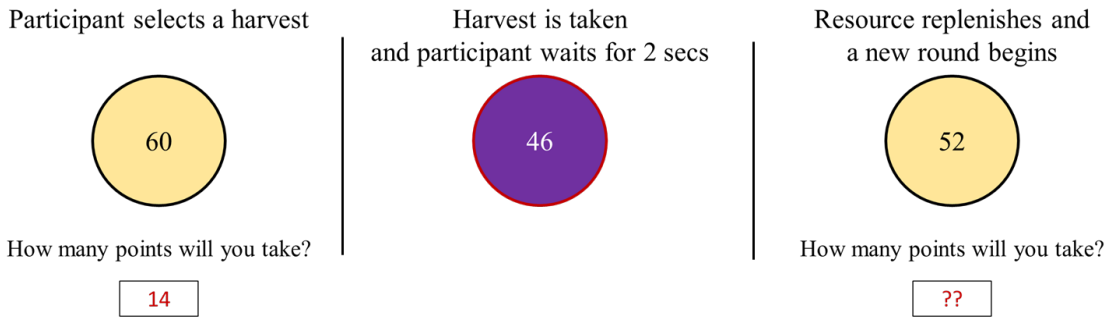


*Figure 1 Flow chart of a round of play during the single-player resource management game.* ***Left:*** *First, participants see a resource with 60 points and may take any number of points.* ***Middle:*** *the points are then removed, and the participant waits for two seconds.* ***Right:*** *Finally, the resource replenishes, and the next harvesting phase begins.*

the resource (Knapp & Clark, 1991; Moxnes, 2000) or (ii) stochastic percentages of the remaining resource (Brechner, 1977; Messick & McClelland, 1983), truncating the replenished value if it grows the resource beyond a maximum bound. Here, we reasoned that a simple bell-curve replenishment function (that offers a 100% replenishment rate for harvests of half the resource) might not be sufficiently challenging to differentiate participants' performance in our game. We wanted to evaluate behaviour on a resource that was sufficiently vulnerable to overharvesting. Therefore, we opted for a stochastic mechanism that, following each harvest, drew replenishment values from a Gaussian distribution ($\mu = 15\%$; $\sigma = 3\%$). Since these replenishments were based upon the value of the remaining resource, participants could maximise their total rewards gathered by making modest (rather than aggressive) harvests (please see below for a more detailed discussion of optimal harvesting behaviour).

The game ended when participants exhausted the resource completely or after 70 rounds. Participants were not told the replenishment rate or the maximum number of rounds. To succeed, participants had to try to estimate the replenishment rate on the basis of exploring

the impacts of harvesting behaviours on the available resource, all the while paying long-term costs if they harvested too much (e.g. it might also take several rounds of not harvesting or minimal harvesting to restore the resource once it is severely depleted).

Before starting the game, participants were told that there that if they depleted the resource quickly, they would have to wait up to 5 minutes before proceeding with the rest of the protocol. Unbeknownst to participants, if they exhausted the resource completely before round 50, they had to wait 6s for every round remaining between the round the resource depleted to zero and round 50 (so, for example, if they depleted the resource at round 10, they would have to wait 4 minutes before proceeding; 40*6 = 240 seconds). In such an instance, the participant was shown a timer which counted down to zero, and the 'Next' button was disabled until the counter reached zero (please see Supplemental Material A for more details). This arrangement was adapted from previous experiments with delay discounting elicitations (Sonuga-Barke et al., 1992) to mitigate the impacts of participants' general delay aversion and moderate the relative value of 'opportunity costs' to do other things once participants had completed the game. In other work, we have demonstrated that this incentivizing mechanism increases engagement when playing the resource management game, since it was in the participants' best interest to learn to maintain the resource (Rauwolf & Rogers, under review).

*Optimal harvesting behaviour:* Importantly, the game was created such that optimal play involves sustaining the resource at a high level. The optimal policy was calculated by framing the resource management game as a Markov Decision Process (Bellman, 1957; Sutton & Barto, 2018). Dynamic programming was then used to evaluate the best harvesting action to take at each possible value of the resource (please see Supplemental Material B for an in-depth discussion of the process) (Bellman, 2010; Puterman, 1994). In this case, the optimal

strategy is to harvest zero if the resource has a value of 51 or less. If the resource has a value above 51, the optimal harvesting behaviour is to harvest the resource down to a value of 51. Given that the resource replenishes more points when the resource has a larger value, but also cannot grow above 60, aiming for a resource value of 51 strikes the perfect balance between harvesting as many points as possible while still allowing the resource to replenish close to its maximum level each round. Such a sustainable strategy maximizes the long-term earnings of a player.

*Psychometric measures*

Following the game, participants completed a subset of the following self-assessments: (i) GHQ-12: (Goldberg et al., 1997), (ii) AUDIT: (Reinert & Allen, 2002), (iii) $ED_{50}$: (Koffarnus & Bickel, 2014), (iv) OECD financial literacy questionnaire - OECD: (Čonková, 2014) and (v) WHO-5: (Hall et al., 2011; Topp et al., 2015).

*Psychological Distress:* The General Health Questionnaire (GHQ) was originally developed to help identify psychological distress (Goldberg & Blackwell, 1970). We used the short-form, twelve-item unidimensional version that captures psychiatric dysfunction in three domains: social dysfunction, anxiety, and loss of confidence (Graetz, 1991; Hankins, 2008). The measure is well-validated against longer versions of the GHQ (Goldberg et al., 1997).

*Hazardous Alcohol Usage:* The Alcohol Use Disorders Identification Test (AUDIT) was developed as a 10-item screening questionnaire to assess harmful alcohol usage (Saunders, Aasland, Babor, et al., 1993). It has been widely used in community and clinical samples and shows good construct and criterion validity (Reinert & Allen, 2002, 2007).

*Delay Discounting:* Delay discounting is the tendency to devalue rewards (i.e. discount them) the longer one has to wait for the delivery. High delay discounting (i.e. the tendency to devalue rewards steeply as a function of time) is associated with several health risk-factors and adverse health experiences (Story et al., 2014). These include hazardous patterns of alcohol use (Petry, 2001), substance misuse (Kirby et al., 1999), obesity and associated metabolic disorders (Barlow et al., 2016), and gambling (Madden et al., 2011). The $ED_{50}$ elicitation consists of 5 forced-choice items asking participants whether they prefer $500 now or $1000 at some later delay. The $ED_{50}$ finds the delay (between 1 hour and 25 years) that devalues a reward by 50% (Koffarnus & Bickel, 2014).

*Financial Literacy:* Financial literacy is identified by the International Network on Financial Education (INFE) as 'a combination of awareness, knowledge, skills, attitude and behaviour necessary to make sound financial decisions and ultimately achieve individual financial well-being' (OECD, 2018). Financial literacy is known to correlate with financial well-being (Taft et al., 2013). We used a short form of the OECD financial literacy survey (Čonková, 2014).

*Well-being:* The World Health Organization Five Well-Being Index (WHO-5) is a short-report measure of subjective well-being. It has been shown to be a good screening tool for depression (Topp et al., 2015) and correlate of subjective quality of life (Hall et al., 2011).

### *Procedure*

Participants read a brief information page and provided informed consent (see Supplemental Material A for full details and screen displays of the protocol). Next, participants completed a couple of demographic questions (i.e. gender and age). Then, they completed a short informational session on the resource management game. Following this, participants were

asked three questions to demonstrate their understanding of the game. They were not able to continue until they had answered these questions correctly, repeating the information session until they demonstrated their understanding of how to play the game (see Supplemental Material A). Participants then played the resource management game. Upon completion, participants were asked a few questions about their strategy and how they felt after playing the game (these questions were exploratory and not considered in the analysis – please see Supplemental Material A for more details).

Next, participants completed various psychometric measures. Data collection was completed in two waves. In the first wave, 200 participants completed the (i) $ED_{50}$, (ii) GHQ-12, (iii) AUDIT, and (iv) WHO-5. In the second wave, 200 participants completed the elicitations for (i) $ED_{50}$ and (ii) financial literacy. Finally, participants were informed of the bonus money they had earned, debriefed, and told they would be paid shortly. All data can be found here: https://osf.io/8b7av/?view_only=075259b34db4412cbf859562cf384eed

**Results**

Internal consistency of the questionnaire scores was generally excellent, with Cronbach's α's of: 0.87 (GHQ-12), 0.95 (AUDIT), and 0.92 (WHO-5). The one exception was the measure of financial literacy, but this remained within acceptable ranges: $\alpha = 0.76$. We considered two outcome measures: (i) the number of rounds sustained with a positive resource value and (ii) the total rewards harvested. Figure 2(left) shows the proportion of participants still sustaining the resource over 70 rounds of the single-player game. As expected, there was large variation in outcomes across the sample. Whilst over 25% of participants completely depleted the resource by round 10, 36% maintained the resource over all 70 rounds.

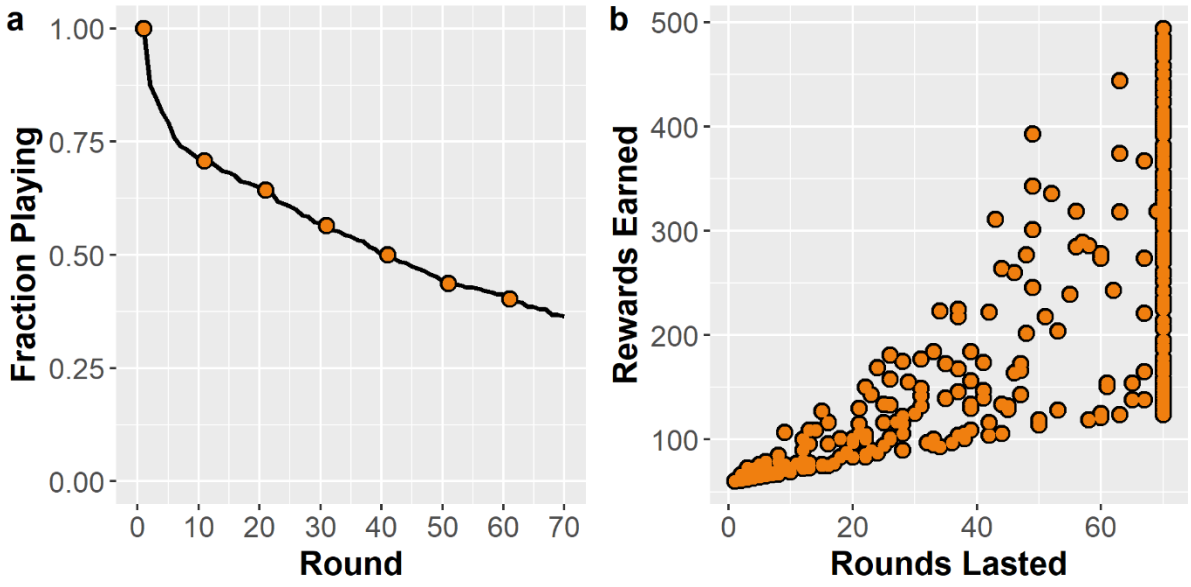


*Figure 2* ***Left:*** *Proportion of participants still playing after a given round.* ***Right:*** *Relationship between rounds lasted and rewards earned for each participant.*

Figure 2(right) illustrates the variation and heteroskedasticity in the total rewards collected relative to the number of rounds lasted. While total rewards were strongly associated with the number of rounds lasted (Spearman's Rank-Order: $r_s(398)=0.88$, $p=2.2\text{x}10^{-16}$), the Breusch-Pagan test for heteroskedasticity showed that this association weakened among individuals who sustained the resource for longer (Breusch-Pagan=153.76, $p=2.2\text{x}10^{-16}$). So, among participants who sustained the resource for the whole game, some collected almost 500 rewards, while others harvested as few as 125 rewards (which was less than some participants who only lasted 15 rounds). This demonstrates that the total rewards gathered over the course of the game can dissociate from the number of rounds sustained, and that there was large variation in outcomes even amongst those who sustained the resource across all 70 rounds of the game. Thus, while many participants were able to last the maximum number of rounds, very few were able to approach the maximum number of rewards earned.

Next, we tested whether this variation in resource outcomes could be explained by health experiences. AUDIT scores indicated highly variable but overall borderline harmful alcohol use (Mean: 9.8±10.1). Similarly, GHQ-12 scores and WHO-5 scores indicated threshold psychological distress and moderate well-being (14.7±5.1 and 12.2±6.5, respectively). As expected, delay discounting rates (calculated as log of k) showed significant variability (-4.4±2.8), but financial literacy less so (34.3±5.8). The dataset did not meet several of the assumptions for parametric analysis techniques (see Supplemental Material C for an in-depth analysis and discussion). As such, we used two non-parametric techniques to evaluate whether resource outcomes from the single-player game showed significant associations with health experiences.

First, we evaluated the associations between each resource outcome and each psychometric variable using Spearman's rank correlation. Participants who reported more hazardous alcohol use sustained the resource for fewer rounds ($r_s(198)=-0.59$, $p=2.2\text{x}10^{-16}$) and harvested fewer rewards ($r_s(198)=-0.56$, $p=2.2\text{x}10^{-16}$). Gignac and Szodorai (2016) recommend that individual difference researchers refer to correlations of 0.1, 0.2, and 0.3 as small, medium, and large, respectively. Therefore, since Spearman's rank correlation ($r_s$) was greater than .3, there was a large effect between hazardous alcohol use and the two resource outcomes. For brevity, scatterplots of the data can be found in Supplemental Material D.

Participants who reported recent psychological distress (as GHQ-12 scores) also sustained the resource for fewer rounds and accumulated fewer rewards over the course of the game ($r_s(198)=-0.19$, $p=.007$ and $r_s(198)=-0.18$, $p=.014$, respectively), demonstrating a medium-small effect. By contrast, better financial literacy was associated with sustaining resources for

longer ($r_s$(198)=0.35, $p$=3.81x10$^{-7}$) and gathering more rewards ($r_s$(198)=0.28, $p$=4.53x10$^{-5}$) – a large-medium effect-size. Similarly, better well-being (as WHO-5 scores) was associated with sustaining the resource longer (and $r_s$(198)=0.23, $p$=.001) and gathering more rewards ($r_s$(198)=0.18, $p$=.009) – a medium-small effect. Please see Supplemental Material D for visuals.

As expected, steeper discounting rates were linked to early depletion of resources ($r_s$(398)=-0.31, $p$=1.39x10$^{-10}$) and fewer rewards gathered ($r_s$(398)=-0.27, $p$=4.07x10$^{-8}$) – a large-medium effect. Consistent with other reports (Sze et al., 2017), steeper delay discounting rates were correlated with hazardous alcohol use ($r_s$(198)= 0.41, p=1.48x10$^{-9}$). However, partial Spearman correlations showed that early exhaustion of the resource (to zero) and fewer rewards gathered over the course of the game remained linked to both hazardous alcohol use ($r_s$(197)=-0.38; p=1.25x10$^{-7}$; $r_s$(197)= -0.41, p=1.39x10$^{-8}$) and psychological distress ($r_s$(197)=-0.18, p=.019; $r_s$(197)=-0.17; p=.023) even when delay discounting rates were controlled for statistically by adding it as a covariate (Liu et al., 2018). Similarly, both resource outcomes remained linked to better financial literacy ($r_s$(197)=0.26, p=.0006; and $r_s$(197)= 0.21, p=.0039) when controlling for delay discounting. These observations show that variable resource outcomes amongst those vulnerable to adverse health experiences are not simply a matter of elevated impulsivity in the form of steeper delay discounting rates.

While the Spearman's correlations indicate general associations, the relationships between resource outcomes and characteristics were non-uniform across performance. To analyse the relationships at various levels of performance, we employed quantile regression (Koenker & Bassett, 1978). Like ordinary least squares (OLS) regression, quantile regression fits a line

through data points to model the relationship between independent variables and a dependent variable. However, the quantile regression line is fit differently compared to OLS regression. In quantile regression, the line minimises the weighted distances between observed values and the values predicted by the model such that a certain proportion of the data points fall above and below the regression line. For example, a quantile regression line fit for the 0.2 quantile is fit such that 20% of the data points lie below the line, while a quantile regression line fit for the median (the 0.5 quantile) is fit such that 50% of the data lie below the regression line (Cook & Manning, 2013; Koenker & Hallock, 2001). Similar to OLS regression, equations can then be constructed for these lines, where the regression coefficient represents the predicted rate of change in the dependent variable per unit change in an independent variable for that specific quantile (Cade & Noon, 2003).

Here, for each questionnaire measure and dependent measure pair, we computed quantile regression models for the 0.05 to 0.95 quantiles, in increments of 0.05. For these models, we normalized the questionnaire scores to a mean of 0 and a standard deviation (SD) of 1. This allowed comparison across models involving questionnaires with different maximum scores. In the resulting models, the regression coefficients at each quantile represent the estimated change in the dependent variable (rounds lasted or total rewards collected) for an increase of one SD in an individual characteristic.

Figure 3 shows the associations between the individual characteristics and both rounds lasted (a and c) and total rewards collected (b and d), at different levels of performance. Each dot represents the regression coefficient of the change in rounds lasted or rewards gathered for an

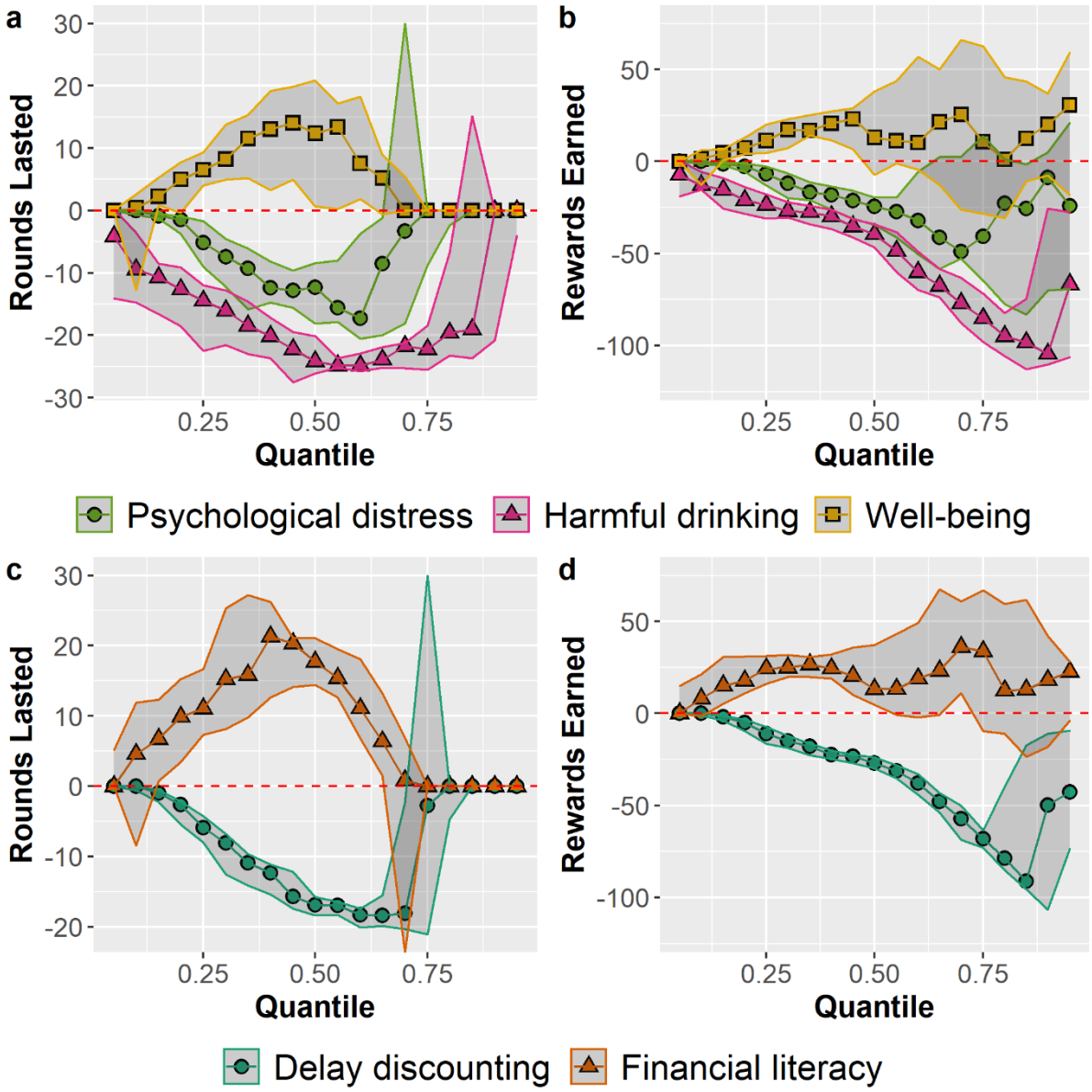


*Figure 3 Quantile regression coefficients for normalized (mean=0; SD=1) harmful alcohol usage (AUDIT), psychological distress (GHQ-12),well-being (WHO-5), delay discounting ($ED_{50}$) and OECD financial literacy scores when predicting rounds lasted **(a & c)** and rewards gathered **(b & d)** from quantiles 0.05-0.95 in increments of 0.05. Shaded areas represent 95% CIs.*

individual characteristic at that quantile. The translucent bands represent 95% confidence intervals for these regression coefficients at each quantile (Koenker, 1994). For example, looking at Figure 3(c), the regression coefficient for financial literacy at the 0.25 quantile was 11 rounds lasted, with a 95% CI [7, 17]. This is equivalent to saying that, at the 0.25 quantile, a participant with a financial literacy score one SD higher than another participant would be

expected to last 11 more rounds in the game. Where the interval does not cross 0 (i.e. dotted red line) in these plots, we can be 95% confident that the resource outcome at that quantile can be predicted on the basis of that characteristic.

Figure 3(a) and (c) show that rounds lasted was significantly associated with all the characteristics around the median; that is, between the 0.20 and 0.70 quantiles. Specifically, at the median, the number of rounds over which individuals sustained the resource was predicted to decrease by 13 rounds for every increase of one SD of psychological distress (Fig 3(a)), by 25 rounds for every increase of one SD of harmful alcohol usage (Fig 3(a)) and by 17 rounds for every increase of one SD of delay discounting (Fig 3c)). By contrast, the number of rounds survived was predicted to increase by 18 rounds for those who were more financially literate (Fig 3(c)) and by 12 rounds for every increase of one SD in general well-being (Fig 3(a)). Most of these associations diminished amongst those who sustained the resource for the longest (> 0.75 quantile) since the best performers survived all 70 rounds, regardless of their characteristics. Please see Supplemental Material D for visualizations of the best fit quantile lines in relation to the raw data.

Figure 3(b) and (d) show the associations between the total rewards collected and characteristics as a function of performance. Negative associations with psychological distress (GHQ-12) are evident among the participants between the 0.25 and 0.60 quantiles. By contrast, we found increasingly negative associations between the total rewards gathered and both increasing hazardous alcohol use and increasing delay discounting across almost all quantiles. The effect was particularly stark among the very best performers. At the 0.85 quantile, 98 rewards might be lost for every increase of 1 SD in hazardous alcohol usage (see Fig 3(b)); similarly, 91 rewards might be lost for 1 SD in delay discounting rate (Fig

3(d)). Finally, among the performers within the 0.10 – 0.50 quantiles, more rewards were gathered with improved well-being and financial literacy (see Supplemental Material D for more visuals).

Experiment 1 demonstrates that individuals' outcomes (in terms of sustaining a resource to facilitate the harvesting of small monetary rewards) in a single-player resource management game vary markedly, and are worse with self-reported recent psychological distress, hazardous alcohol use, and rapid delay discounting. By contrast, the same outcomes appear to be improved among individuals with better self-reported well-being and financial literacy. Overall, the strongest relationships involved hazardous alcohol use (as measured with the AUDIT) and delay discounting (as the rates elicited by the $ED_{50}$). Importantly, the links between resource outcomes and hazardous drinking (and indeed psychological distress) do not appear to be artefacts of covarying rapid delay discounting. This is because the former associations survived correction for participants' discounting rates. In Experiment 2, we consolidate these findings with a direct replication.

**Experiment 2**

In Experiment 2, we sought to replicate the effects of delay discounting and harmful alcohol usage found in Experiment 1. Participants played the same single-player resource management game as above. They then took two psychometric questionnaires: the 10-item Alcohol Use Disorders Identification Test (AUDIT: Saunders, Aasland, Babor, et al., 1993) and the 5-item $ED_{50}$, delay discounting elicitation (Koffarnus & Bickel, 2014). Experiment 2 was part of a larger set of experiments, reported elsewhere, that addressed a distinct research

question (Rauwolf & Rogers, under review). However, this is the first time this dataset has been used to consider the effect of individual characteristics on resource outcomes.

## Method

### *Participants*

Ethical approval for this experiment was granted by the Bangor University Psychology Research Ethics Committee. Three hundred and eighty-one participants took part, recruited from Amazon Mechanical Turk. As in Experiment 1, participants completed an online protocol hosted on Qualtrics. The sample consisted of 158 females, 222 males, and 1 participant who preferred not to identify their gender. Participants had a mean age of 35.3±10.7yr. No participant was excluded.

The experiment was only made available to MTurk workers based in the United States of America with at least a 95% approval rating from previous tasks. Participants were paid a base fee of $0.75 for participating and told they could earn a bonus payment up to value of $6.00. They could earn up to $3.00 depending on their performance in the single-player game, and another $3.00 for a different game which is not described here. As in Experiment 1, participants were not told the value of each reward harvested in the game ($0.005) until they had completed the entire experiment. Of note, after the experiment, we calculated that participants earned an average bonus of $0.76 ± $.59(SD) for the single-player game (bonus payments ranged from $0.30 - $2.53). Using the time it took for each participant to complete the protocol, along with all bonus payments, the average rate of pay was $7.74± $4.05 per hour.

### *Materials*

The materials were similar to those used in Experiment 1. Participants played a resource management game (see Experiment 1 and Figure 1). Then, participants completed measures of harmful alcohol use (AUDIT) and delay discounting ($ED_{50}$) – please see Experiment 1 for more details on these measures.

### *Procedure*

First, participants were presented with an information sheet and completed a consent form (please see Supplemental Material A for full details of the experimental procedure). Next, participants answered a couple of demographic questions (age and gender). As in Experiment 1, participants were given instructions on how to play the resource management game. Prior to playing the game, participants had to correctly answer four questions, demonstrating understanding of the game. Participants then played the resource management game. Upon completion, if they accrued a time-penalty for depleting the resource early, they had to wait before proceeding. Then, participants were informed of how much bonus money they had earned. As this experiment was part of a multi-faceted procedure, the participants then played a different game, which is not considered in this work. Afterwards, participants completed the $ED_{50}$ followed by the AUDIT. Finally, participants were debriefed, reminded of how much bonus money they had earned, and told they would receive payment within 72 hours. All data can be found here: https://osf.io/8b7av/?view_only=075259b34db4412cbf859562cf384eed

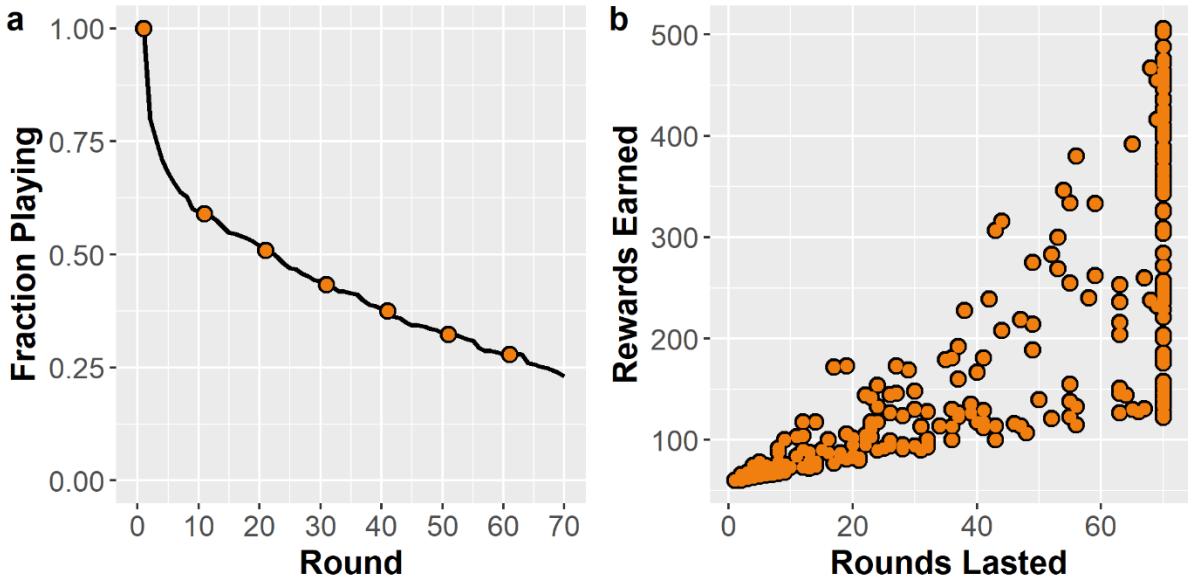


*Figure 4* ***Left:*** *Proportion of participants still playing after a given round.* ***Right:*** *Relationship between rounds lasted and rewards earned for each participant.*

**Results**

The data showed significant heteroskedasticity (see Supplemental Material C), so data analysis was completed with the same statistical tests as Experiment 1. Figure 4(left) shows the proportion of participants still sustaining the resource at each of the 70 rounds of the resource management game. 41% of participants fully exhausted the resource by round 10, while 23% maintained the resource across the maximum 70 rounds. Figure 4(right) shows how, as in Experiment 1, the variation in rewards gathered increased with the number of rounds lasted. While many participants were able to last the maximum 70 rounds, few were able to harvest a large number of rewards.

Next, we explored the relationships between resource outcomes and (i) harmful alcohol use (M: 12.03, SD: 11.05), and (ii) delay discounting (calculated as log of k; M: -3.34, SD: 3.27).

The responses to the AUDIT questionnaire showed excellent internal consistency, with a Cronbach's α of 0.95.

Non-parametric Spearman correlations showed that participants reporting hazardous alcohol use tended to sustain the resource for fewer rounds ($r_s(379)=-0.54$, $p=2.2\text{x}10^{-16}$) and gather fewer rewards ($r_s(379)=-0.52$, $p=2.2\text{x}10^{-16}$). These effect sizes ($r_s$) are very similar to Experiment 1, replicating the large effect of harmful alcohol use. Similarly, participants with steeper discounting rates also sustained the resource for fewer rounds of the game ($r_s(379)=-0.34$, $p=9.33\text{x}10^{-12}$) and gathered fewer rewards ($r_s(379)=-0.31$, $p=3.86\text{x}10^{-10}$). Again, these effect sizes are very comparable to Experiment 1, constituting a convincing replication. As in Experiment 1, partial Spearman correlations showed that, when controlling for delay discounting, harmful alcohol use was still significantly associated with fewer rounds lasted ($r_s(378)=-0.46$; $p=1.61\text{x}10^{-16}$) and rewards earned ($r_s(378)= -0.44$, $p=3.00\text{x}10^{-18}$). For brevity, scatter plots of the raw data can be found in Supplemental Material D.

Finally, we ran quantile regressions to examine these relationships at various levels of performance. As in Experiment 1, each individual characteristic was normalized to a mean of zero and a standard deviation of one. Figure 5 shows the relationships between rounds lasted (Figure 5a), and total rewards gathered (Figure 5b) on both AUDIT scores and $ED_{50}$ discounting rate.

Here, we found similar relationships compared with Experiment 1. Harmful alcohol use (as AUDIT score) was associated with fewer rounds lasted between the 0.15 – 0.80 quantiles and fewer rewards gathered in all quantiles after 0.15. Associations involving delay discounting

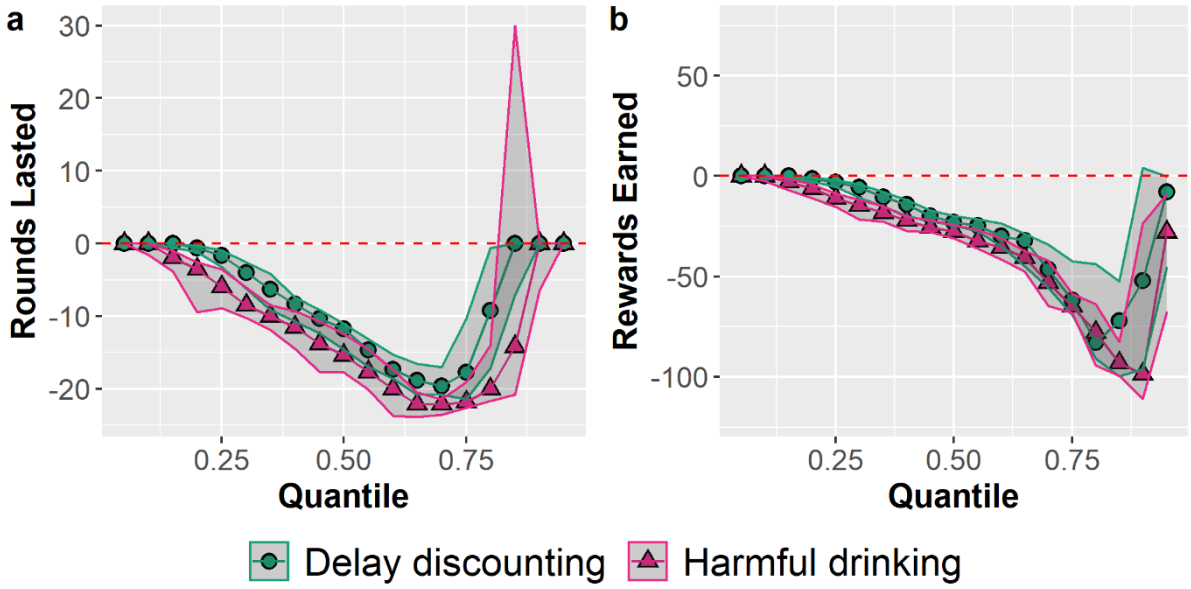


*Figure 5: Quantile regression of rounds lasted (left) and rewards gathered (right) against normalized (mean=0; SD=1) harmful alcohol usage (AUDIT) and delay discounting ($ED_{50}$) from quantiles 0.05-0.95 in increments of 0.05. Shaded areas represent 95% CIs.*

showed similar patterns. Discounting rates (as $ED_{50}$ scores) were associated with fewer rounds lasted between the 0.30 – 0.80 quantiles and fewer total rewards gathered in all quantiles after 0.30. Please see Supplemental Material D for visualizations of the best fit quantile lines in relation to the raw data.

Finally, across the quantiles, the effect sizes were similar to Experiment 1. For instance, the quantile regression models predict that, at the median, the number of rounds lasted would decrease by 15 for every increase of one SD of harmful alcohol use, and by 12 for every increase of one SD of delay discounting. Further, at the 0.85 quantile, participants would be expected to gather 93 fewer points for an increase of one SD of harmful alcohol use and 72 fewer points for an increase of one SD of delay discounting.

**Discussion:**

Encouraging sustainable use of limited natural, social, and economic resources involves understanding the variety of ways in which people think about how resources work and how they adjust their behaviour (or not) as available resources fluctuate. Interpreting the variation in individual behaviours in group-based, common-pool games (as models of resource management; Balliet, 2009; Brewer & Kramer, 1986) is complicated by the difficulty of disentangling responses to the social aspects of sharing resources with other non-social factors. Thus, characterising varying behaviours and outcomes in single-player games can help us to understand more about how individuals engage with resource 'temporal dynamics' (Hendrickx et al., 2001).

Here, for the first time, we show that resource outcomes of a single-player game involving a dynamic resource are moderated by self-reported mental health experiences and delay-discounting rates (as a generic risk-factor). In two experiments with large sample sizes, including one direct replication, we find that the ability to sustain a resource over successive harvesting opportunities is reliably worse in individuals reporting elevated psychological distress and the often co-occurring hazardous alcohol use (Lai et al., 2015). Strikingly, these associations remained substantial once we had accounted for elevated delay discounting rates (as a form of impulsivity; Ainslie, 1975), itself a strong risk factor for alcohol misuse and other health problems (Amlung et al., 2019; Fields et al., 2014; Levitt et al., 2023; Petry, 2001; Story et al., 2014). By contrast, individuals who reported higher levels of financial literacy and general well-being achieved correspondingly better resource outcomes.

Our observations suggest that the capacity to respond effectively to the dynamics of resources are compromised in individuals at risk of psychological and alcohol-related disorders. We

suggest this work has important ramifications for understanding how individual characteristics moderate behaviour in more complex group settings (e.g. common pools). Managing a resource at the group level involves learning complex multi-partner dynamics whilst simultaneously learning non-trivial, time-based resource dynamics (Hendrickx et al., 2001). This work demonstrates that health risk factors are associated with difficulties navigating resource dynamics in a single-player setting, where one does not navigate multi-partner dynamics. Future work in understanding how individual characteristics affect group-based resource maintenance should amalgamate the causes underlying variation of individual resource management behaviours with the complex dynamics caused by multi-partner interactions.

The variation in resource management behaviours reported here might reflect several – possibly overlapping – psychological mechanisms. First, consistent with evidence of aggressive harvesting behaviours when resources are independently devalued with time (Mannix, 1991), it is likely that individuals with high delay discounting rates will have harvested aggressively earlier in the game in order to secure rewards quickly at the expense of later but larger total rewards afforded by a sustained resource (cf. Bechara et al., 1994). However, other inter-related forms of impulsivity might be involved (Dalley & Robbins, 2017; Evenden, 1999). These include the tendency to act prematurely – in this case, harvesting heavily – without reflecting on the potential damage to the resource (Clark et al., 2006). It might, therefore, be helpful to explore whether interventions to promote future-oriented thinking improve resource management in single-player games in the same way as they have been found to produce transient reductions in discounting rates (Bar, 2010; Benoit et al., 2011) and moderate health-relevant behaviours (Dassen et al., 2016).

Further, the observation that resource outcomes were linked to participants' psychological distress and alcohol misuse (even once delay discounting rates had been controlled for) suggests variation in broader cognitive and emotional function linked to psychopathology. Optimal play in our single-player game involves learning about the good and bad outcomes of higher vs lower harvests. However, the motivational processes mediated by this kind of reinforcement learning is likely to be impaired in individuals with anxiety and depression (Browning et al., 2015; Pizzagalli et al., 2008) and subject to broader mood-dependent biases in the processing of positive and negative information (Bradley et al., 1995; Hamilton & Gotlib, 2008; Mennen et al., 2019). Similarly, reward-based learning can also be compromised in groups with alcohol use difficulties (Cao et al., 2021; Park et al., 2010). In the present experiments, we used validated self-report measures to identify increasing risk of psychological disorders. Further work in clinical samples with established diagnoses for mood, anxiety or alcohol use disorders could clarify whether difficulties engaging with resources are linked to symptom severity, persist in the euthymic or remitted state, or are linked to broader difficulties in managing financial, social and clinical resources in patients' lives (Adinoff et al., 2016; Haushofer & Fehr, 2014; Richardson et al., 2017). Finally, the positive links seen here between resource outcomes and financial literacy suggest that the effective use of the resource in our single-player game is linked to broader patterns of planning and cautious decision-making in household and financial contexts as captured by the OECD measure of financial literacy (Čonková, 2014).

These experiments do have limitations. First, our findings involved a single-player game with specific initial resource values (60 nominal rewards) and a particular replenishment value (15±3%). We cannot yet know whether the pattern of harvesting behaviours observed and their modulation by health experiences might be different with different game parameters.

Future work could consider the resource parameters which constitute the boundary conditions for these patterns. Second, although our findings show that resource management outcomes are linked to participants' delay discounting rates, the replenishment mechanism in our single-player game involved stochastic additions to the resource. Therefore, in future work, it might be helpful to explore whether harvesting behaviours are also moderated by individuals' probability discounting rates as a distinct construct (Green & Myerson, 2013).

Third, the use of a stochastic replenishment function meant that participants experienced slightly different fluctuations in the resource. While the resource replenished at 15% on average, some participants would have seen slightly higher or lower replenishments rates compared with others. This could have influenced behaviour in the game – for example, some participants might have experienced low replenishments early while they were learning about the vulnerability of the resource. To test whether resource outcomes reflected variation in experienced replenishment rates, we calculated, for each participant in each experiment, the mean replenishment rate over the first 1, 2, 3, 5, 10, 20, 50, and 70 rounds. We then ran Spearman correlations between the mean replenishment rates across participants and both rounds lasted and total rewards gathered. None of the effects were substantial or statistically significant (see Supplemental Material E for the detailed analysis). Therefore, it seems unlikely that the participants' behaviour in the games were linked to variance in replenishment experiences.

Fourth, in these studies, participants did not know the resource management game would end after 70 rounds. Further, previous research suggests that, in other contexts, manipulating uncertainty around the termination of games can affect risk and delay-related choices (Bigoni

et al., 2015; Pietras et al., 2003; Pietras & Hackenberg, 2001). As such, it is possible that the poor sustainable behaviour observed here among individuals with health risk factors was due to poor navigation of the uncertain termination rule of the game. In other words, perhaps those with health risk factors would manage a resource better if they were certain the resource game would not end abruptly. Using previously unanalysed data from another study, we found that this was not likely to be the case (see Supplemental Material F for complete analysis). Here, 100 participants played the same single-player resource management game but with the number of rounds remaining in the game displayed before each harvest. These participants also completed the $ED_{50}$ measure of delay discounting. As above, the number of rounds sustained and the total rewards gathered were strongly and negatively associated with discounting rates. In fact, the strength of these correlations were larger when participants knew the termination rule of the game compared with when they did not know, as in Experiments 1 and 2. Thus, the associations involving delay discounting rates are not an artefact of participants' lack of knowledge of the game's termination rule.

Finally, there remain important questions about the direction of causality in the poor resource outcomes of individuals reporting adverse health experiences. Possibly, as above, the behaviours seen in the present experiments directly reflect changes in the cognitive and affective mediators of symptom severity. However, equally, social and economic difficulties are linked to elevated rates of depression, anxiety and alcohol misuse (Haushofer & Fehr, 2014; Makela, 1999; Marmot, 1999; Richardson et al., 2017; Sze et al., 2017). Prolonged, psychosocial pressures of this kind can undermine resilience, possibly promoting 'fast-life strategies' that, in a context of uncertainty and scarcity, prioritise the rapid consumption of resources which can further elevate stress and the likelihood of relapse or symptom severity (Pampel et al., 2010; Pepper & Nettle, 2017). As such, it may be helpful to focus future

research on psycho-education interventions to include content about resource dynamics to support individuals reporting psychological distress in the effective management of their financial, social, and clinical resources in order to protect their well-being. It may also be helpful to tailor policy interventions to encourage sustainable use of resources, allowing for the difficulties that clinical groups may experience with resource dynamics.

**Open Practices Statement:**

All data analysed in this study is available and can be found here: https://osf.io/8b7av/?view_only=075259b34db4412cbf859562cf384eed. This study was not pre-registered.

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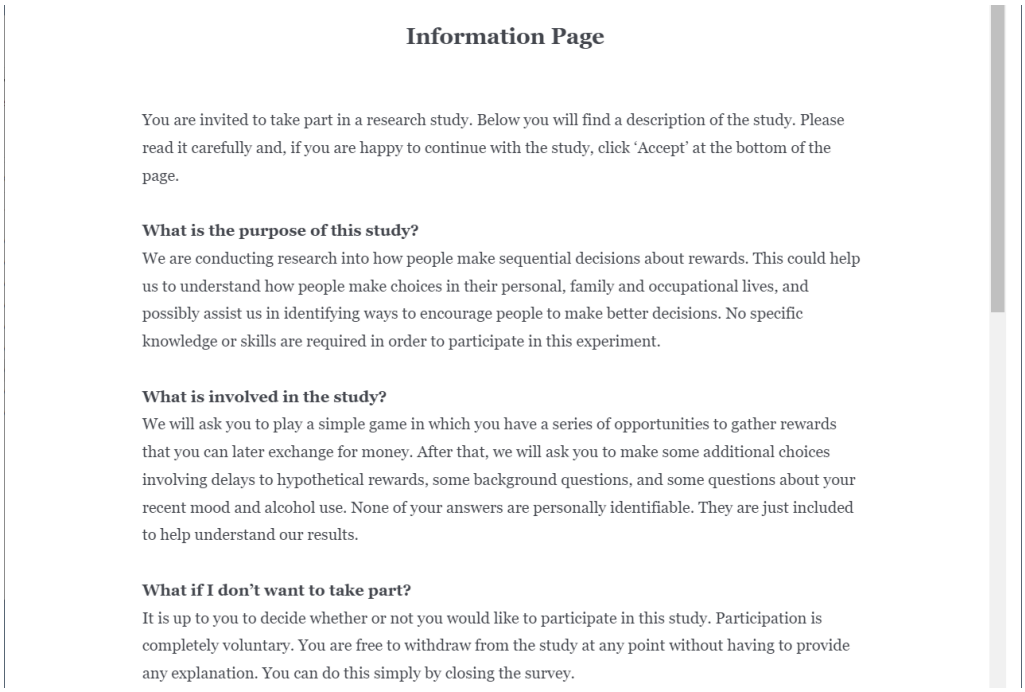
## Supplemental Material A– Materials

Below is a detailed description of the experimental protocols for both experiments, including screenshots of each stage of the procedure in each experiment.

### ***Experiment 1***

### Participant information page and consent form:

Prior to completing the protocol, the participant needed to consent to participate. To do this, each participant was shown the below Information Page. At the end of the page, they agreed to several bullet points (e.g., that they knew they could quit at any point by closing the experiment). The participant agreed to the consent form by clicking 'Accept' at the bottom of the page.



**Information Page**

You are invited to take part in a research study. Below you will find a description of the study. Please read it carefully and, if you are happy to continue with the study, click 'Accept' at the bottom of the page.

**What is the purpose of this study?**
We are conducting research into how people make sequential decisions about rewards. This could help us to understand how people make choices in their personal, family and occupational lives, and possibly assist us in identifying ways to encourage people to make better decisions. No specific knowledge or skills are required in order to participate in this experiment.

**What is involved in the study?**
We will ask you to play a simple game in which you have a series of opportunities to gather rewards that you can later exchange for money. After that, we will ask you to make some additional choices involving delays to hypothetical rewards, some background questions, and some questions about your recent mood and alcohol use. None of your answers are personally identifiable. They are just included to help understand our results.

**What if I don't want to take part?**
It is up to you to decide whether or not you would like to participate in this study. Participation is completely voluntary. You are free to withdraw from the study at any point without having to provide any explanation. You can do this simply by closing the survey.

**What will happen to my data?**
We may use the results to write an academic paper. This and any other publications will not identify you individually. All data collected will be treated in the strictest confidence. The data will be stored securely for 7 years. If you choose to withdraw from the study and your data is identifiable to the research team, you have the right to request that your data is not used. Learning about how people manage resources could help us to find ways to assist vulnerable groups and, perhaps, develop sustainability policies.

**Who do I contact for further information?**
If you have any questions or want to leave the study, please email: rdproblems@bangor.ac.uk. We will do our best to answer your queries quickly.

**Is there anything else I should know?**
Since this study is considering individual responses, we can only let you complete the survey once. If you take the survey more than once, you will only get paid for the first study. If you choose to leave the study at any point, all of your data will be removed.

**Who is running the study?**
This survey is run by the School of Psychology (Bangor University).

The study has been approved by the university's Psychology Research Ethics Committee (Study No: 2017-16211).

Dr Paul Rauwolf
Professor Robert D Rogers
School of Psychology
Brigantia Building
Bangor University
LL57 2AS, UK
E-mail: rdproblems@bangor.ac.uk

**Consent Form:**

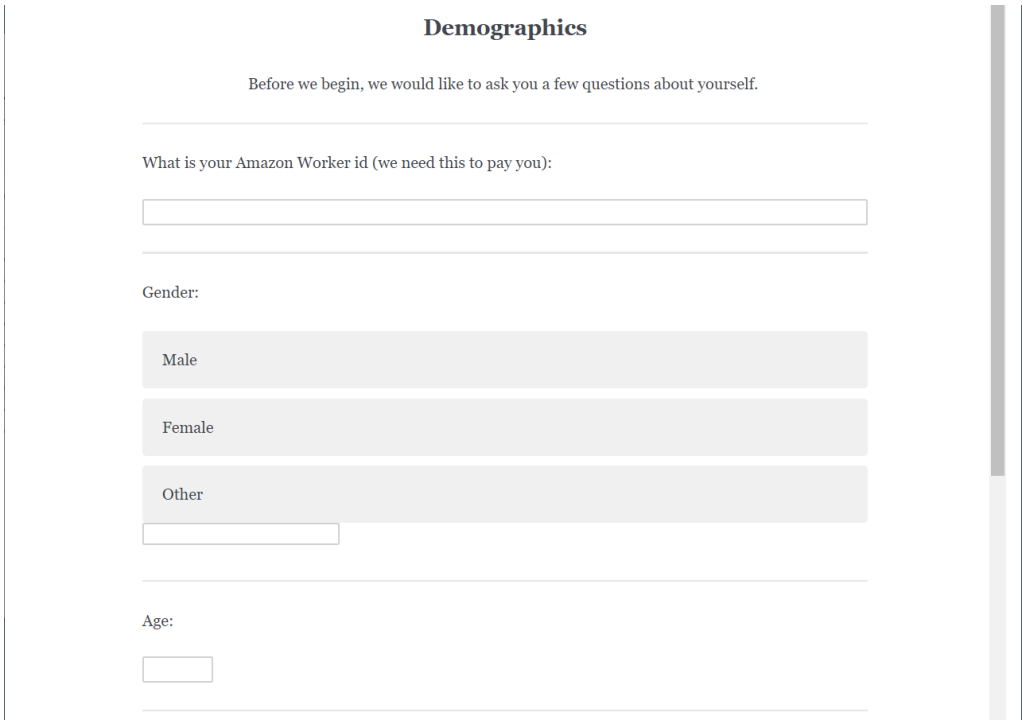
By clicking 'Accept' below, you agree to the following:

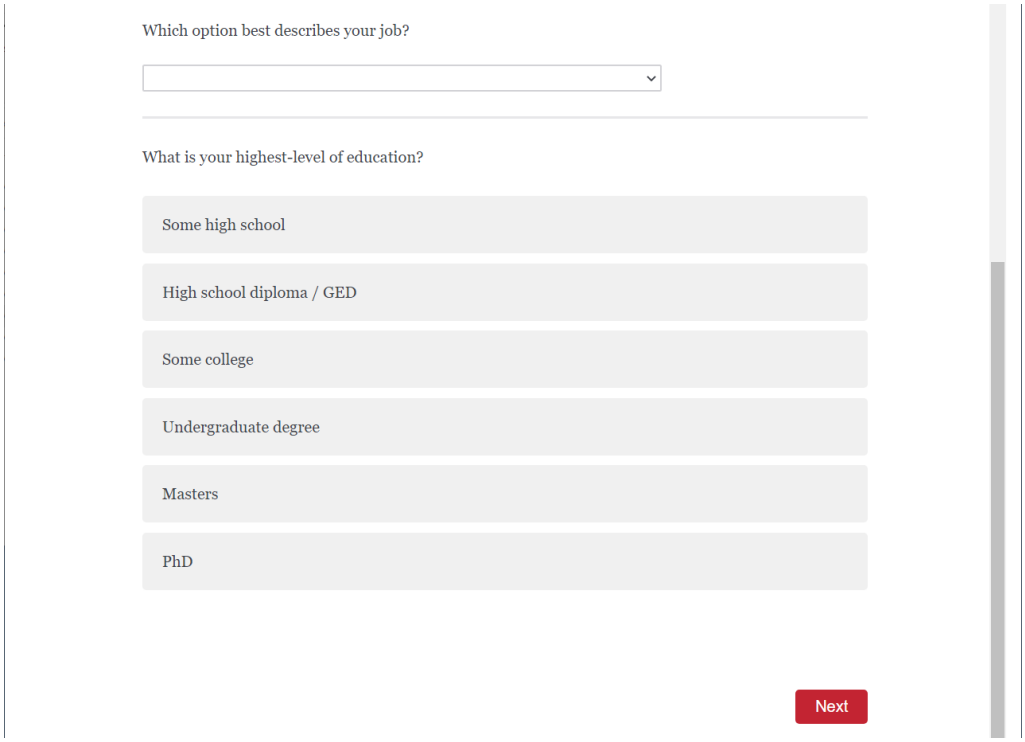
- I have read the information above and understand what is involved in the study.
- I consent for my anonymised responses to be used in academic publications.
- I understand that my participation is voluntary, that I am free to leave the study at any time, and that if I do so, my data will be removed from the study
- I understand that I will only get paid for completing the questionnaire once.
- I understand that Bangor University may wish to audit anonymised data as part of research governance.
- I agree to participate in the study.

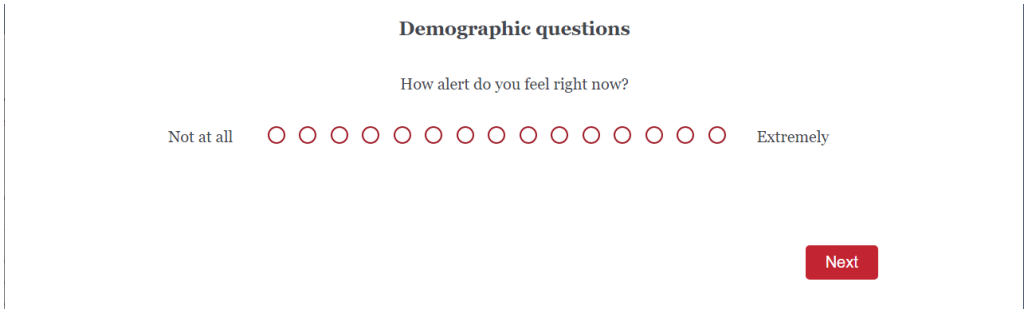
Accept

**Participant demographic information:**

Next, we asked participants some demographic questions.

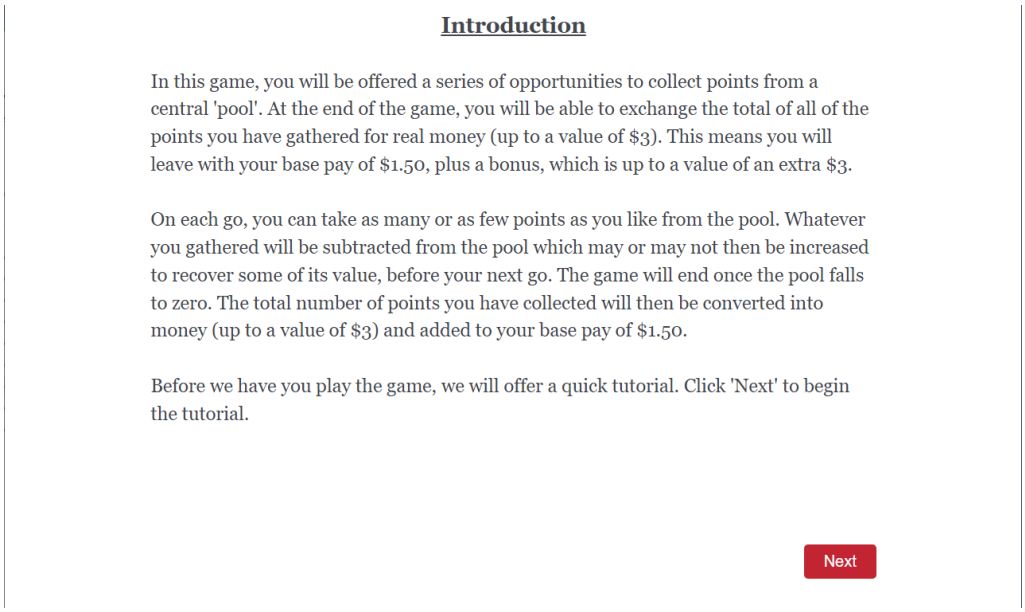



**Instructions:**

Before participants played the game, we offered a tutorial about how the game works and what they were expected to do. We did not tell the participants the replenishment rate, maximum number of rounds, or monetary value of each reward earned. Participants were only told that they could earn a maximum of $3 for their play in the game.



## How does the game work?

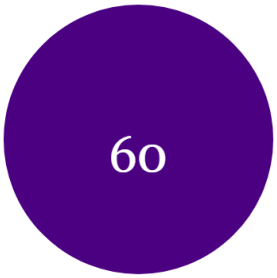
The game consists of several opportunities.

Each opportunity is broken up into 2 parts.
First, you decide how many points to take from the pool.
Second, the pool may receive additional points.

Next

## Training

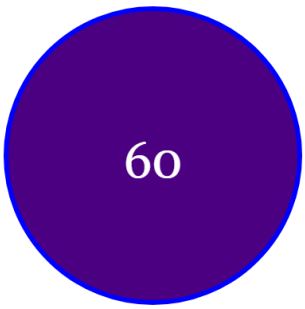
Below is what you will see when you play the game. When you're ready, click the next button and we'll explain what everything means.




How many points would you like to take?

Next

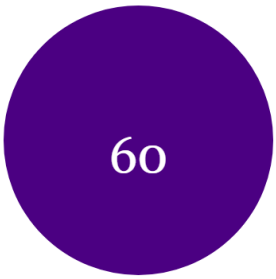
The blue highlighted area represents the pool of points.
You can collect points from this pool.




How many points would you like to take?

Next

Each opportunity, you can choose how many points you wish to take from the pool. The blue highlighted box indicates how many points you will take on this go. You will type a number into this box, and that amount will be removed from the pool and added to your total points.

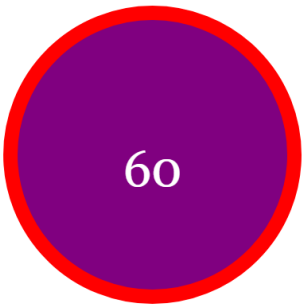



How many points would you like to take?

Next

After you select the amount of points you wish to take, you will need to wait a moment while we:
1.) Gather your requested points
2.) Allow the pool to potentially increase

A red border, like the one below, will appear around the pool whilst we complete these tasks. Usually this screen will disappear after a few seconds, but for training, we'll have you click 'Next' when you are ready.




Next

## Repeat

After you've collected points from the pool, and the pool has been allowed to increase, you will receive another opportunity to collect points. These opportunities to collect points will continue until the game ends.

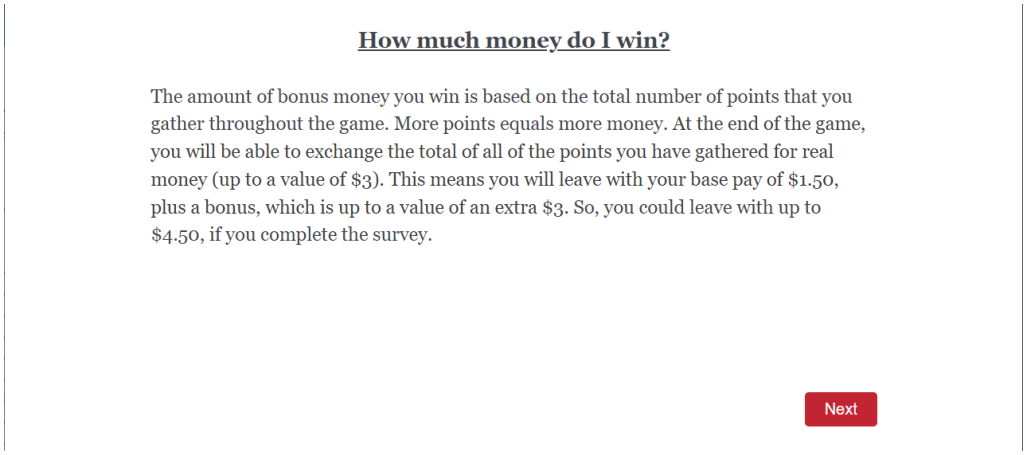
Next

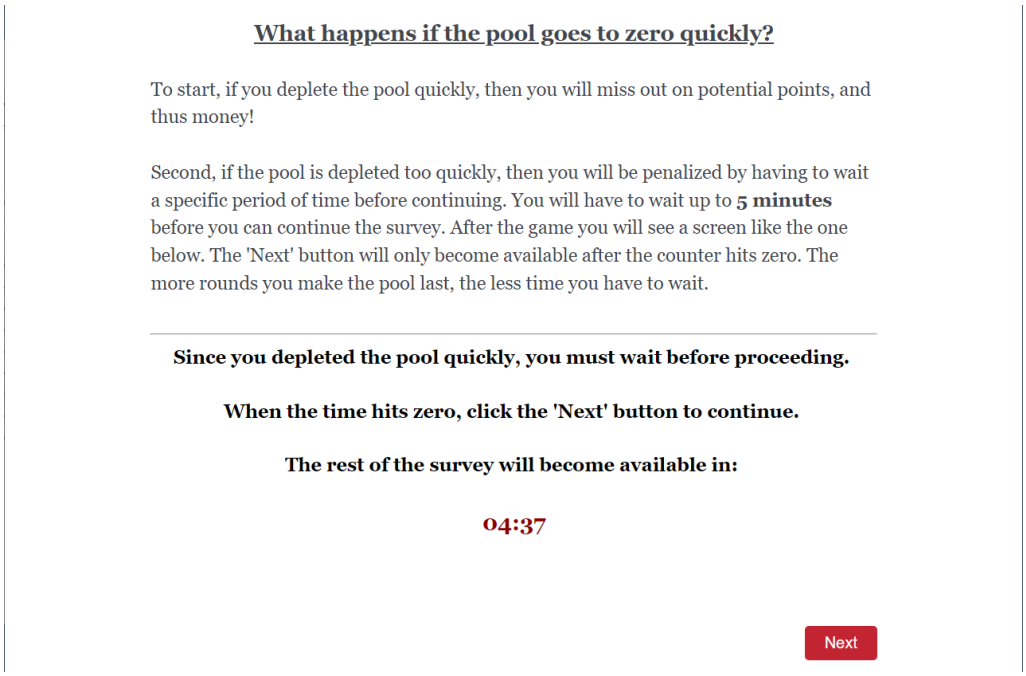
## When does the game end?

The game ends when either:

1.) the pool reaches zero, or
2.) when you've had a number of opportunities to collect points.

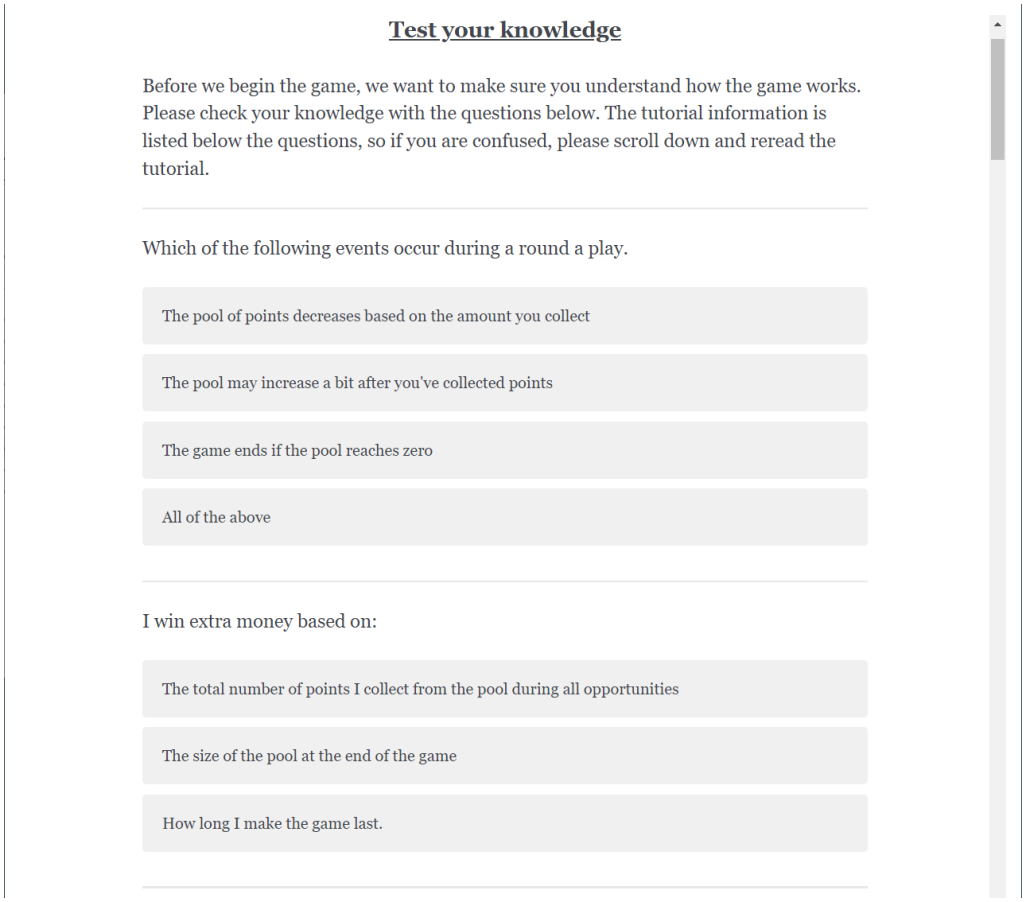
Next

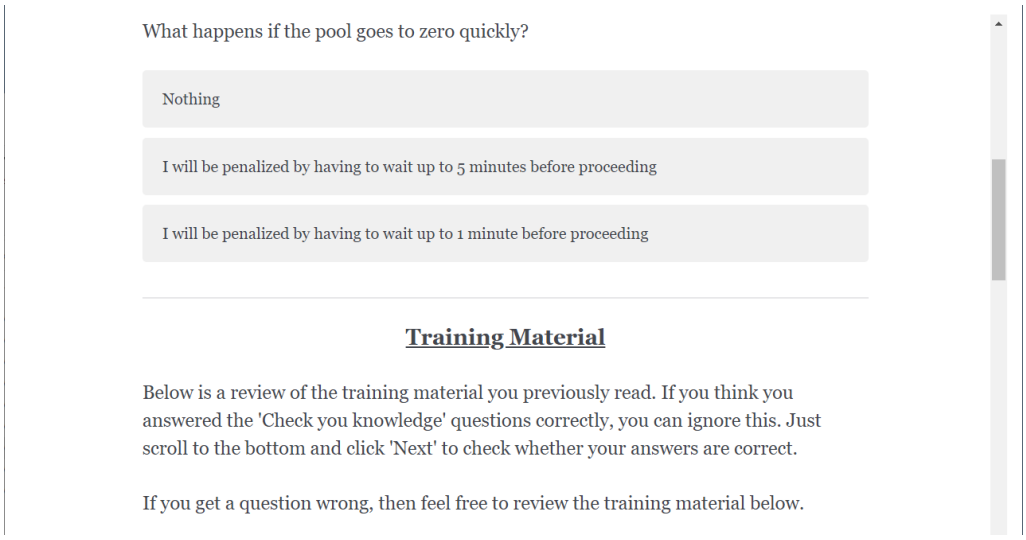



## Questions to assess participant understanding:

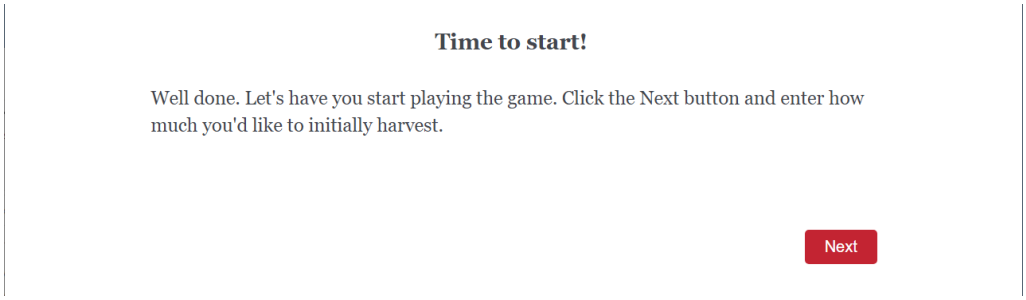
Here, we asked participants three multiple-choice questions to assess their understanding of the game. Participants could not continue past this page until they had selected the correct answer for each of these questions. This page also contained all the instructions previously given to the participant, to revise again if necessary. We haven't included screenshots of this, as the instructions are identical to those shown above.



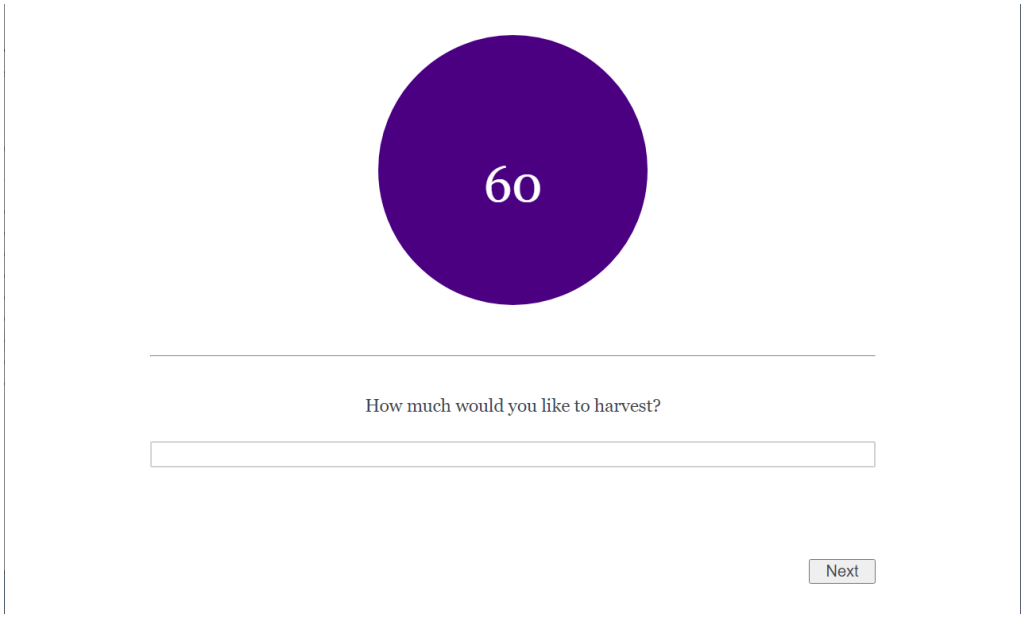




**Playing the game:**

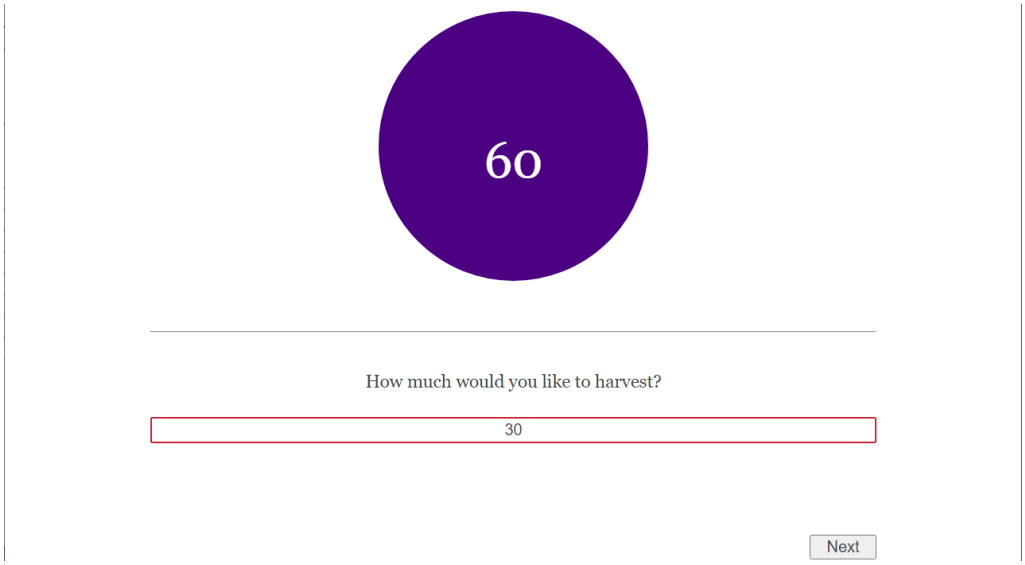
Once they had answered the ‘Test your knowledge’ questions correctly, participants played the game. In these screenshots, we show an example of a participant who lasted two rounds in the game.



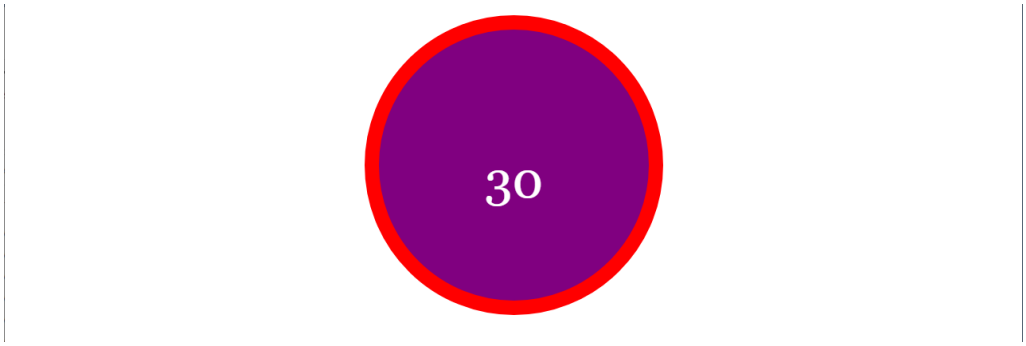

The resource always started at its maximum capacity of 60. Participants typed the number of rewards they wanted to harvest into the text box, and then clicked ‘Next’ to harvest these rewards.




As an example, a participant might take 30 rewards from the resource in the first round.



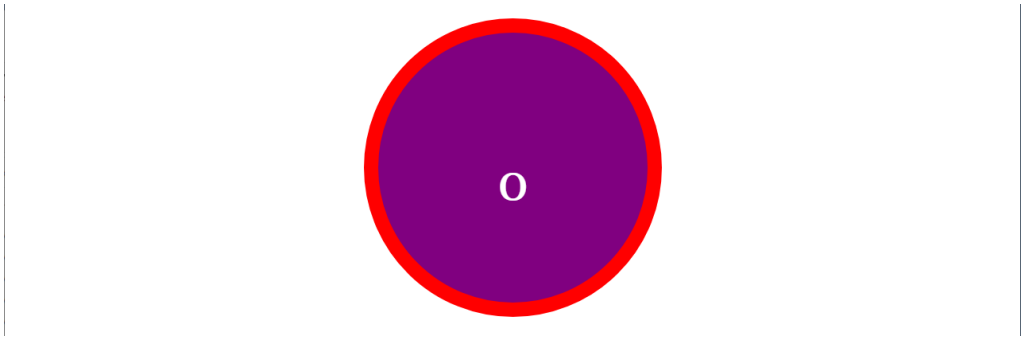

Once the participant clicked ‘Next’, they would see this page for a couple of seconds.



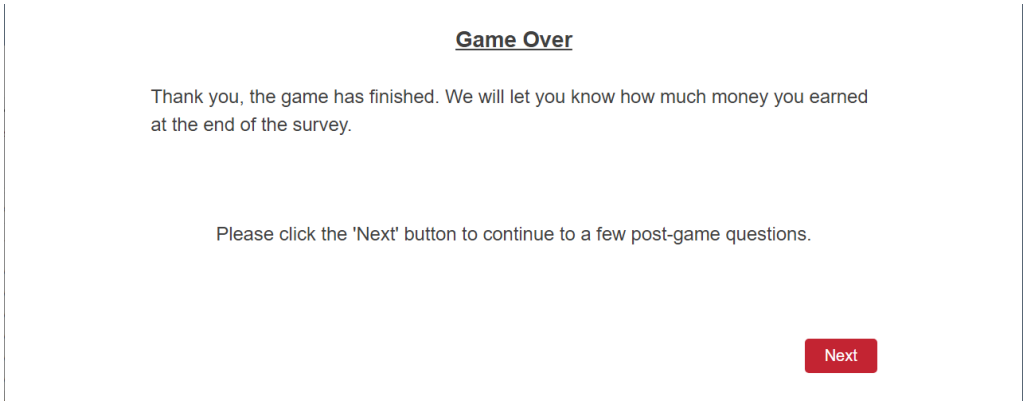

The resource would then replenish by around 15%.

Perhaps, the participant might then choose to harvest the full amount of rewards contained in the pool.

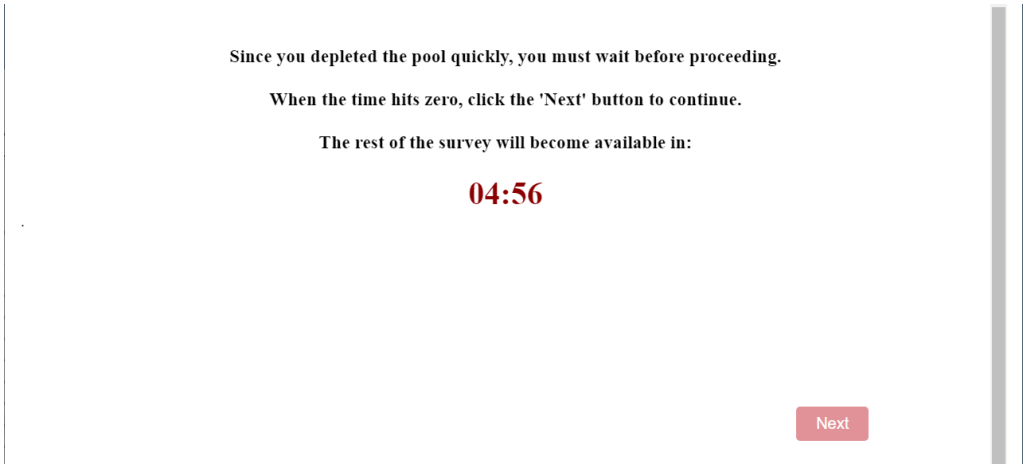

The resource would then be depleted to zero and would replenish no more.




Once the game finished, participants saw this page.

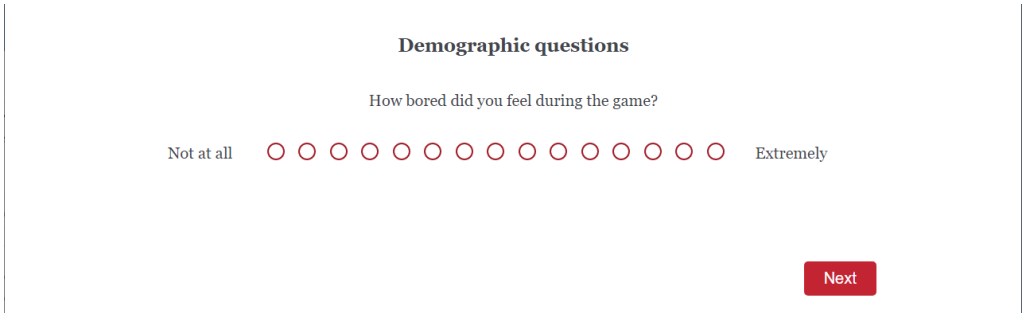


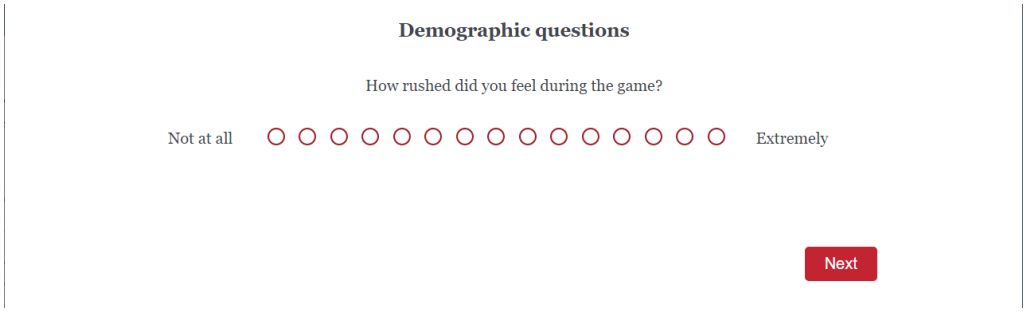
As the participant in our example finished the game before round 50, they would have to wait for a time penalty before they could continue.



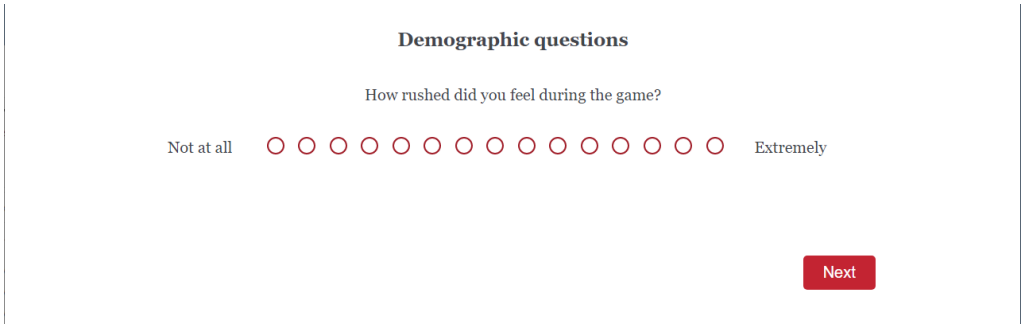

**Post-game reaction survey:**

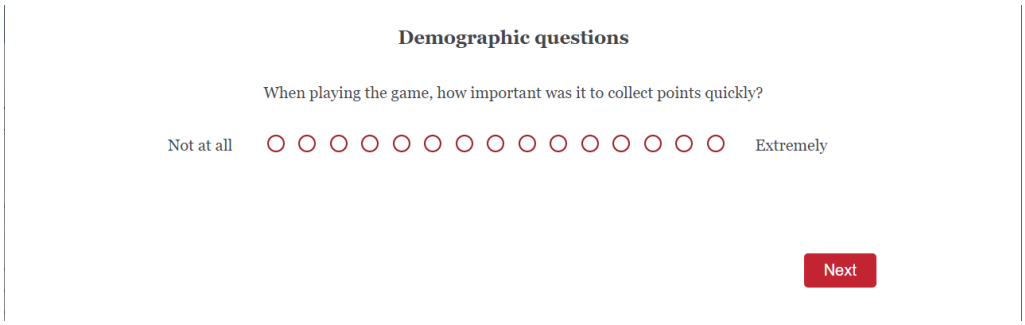
Next, we asked participants some questions about how they felt during and after the game.

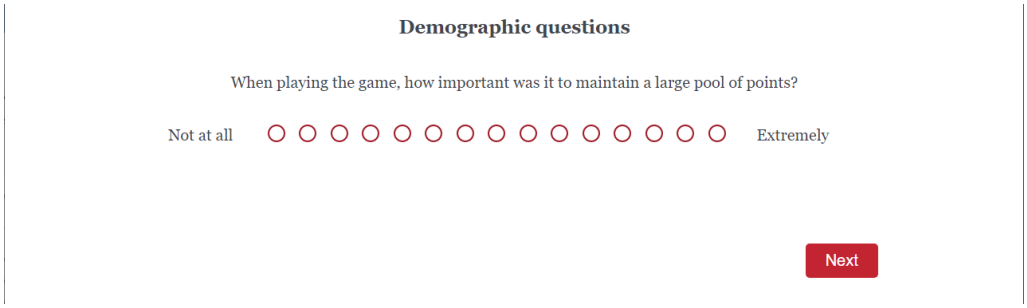


Demographic questions
How bored did you feel during the game?
Not at all
Extremely
Next

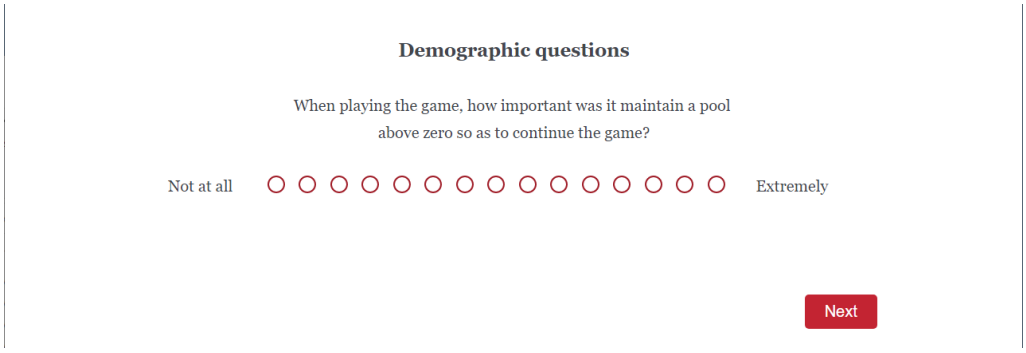

Demographic questions
How rushed did you feel during the game?
Not at all
Extremely
Next


Demographic questions
How frustrated did you feel during the game?
Not at all
Extremely
Next


Demographic questions
How rushed did you feel during the game?
Not at all
Extremely
Next

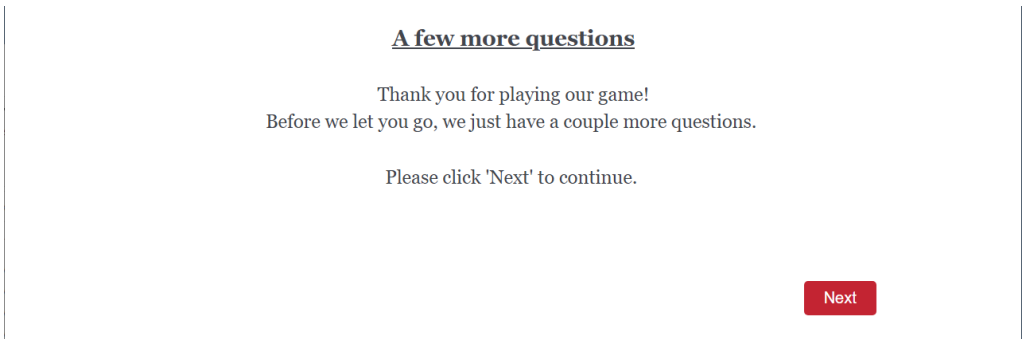

Demographic questions
When playing the game, how important was it to collect points quickly?
Not at all
Extremely
Next


Demographic questions
When playing the game, how important was it to maintain a large pool of points?
Not at all
Extremely
Next

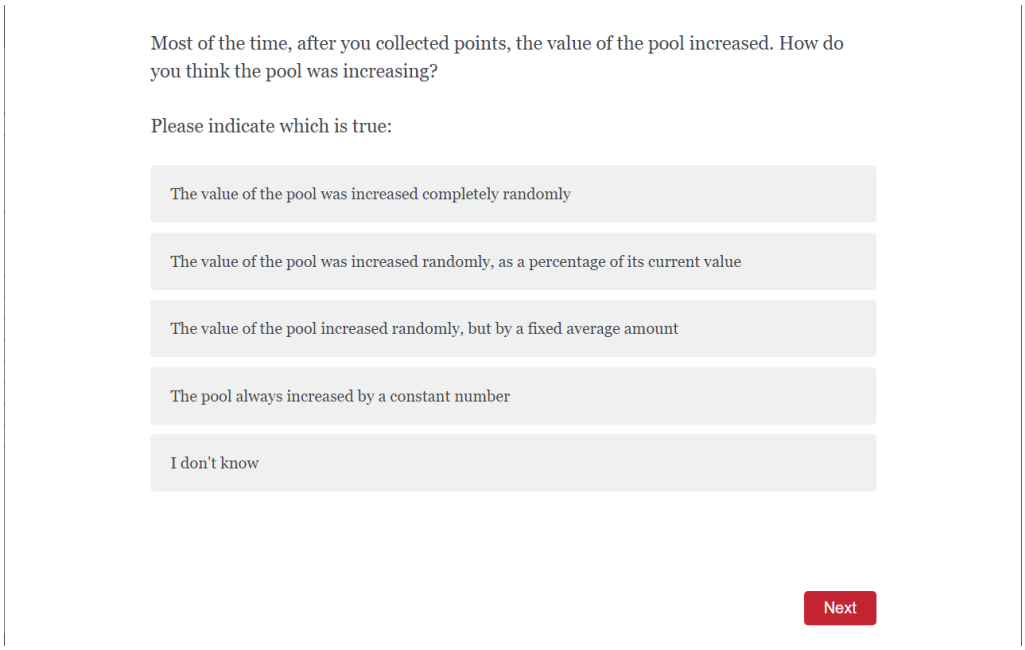

Demographic questions
When playing the game, how important was it maintain a pool above zero so as to continue the game?
Not at all
Extremely
Next

**Post-game understanding questions:**

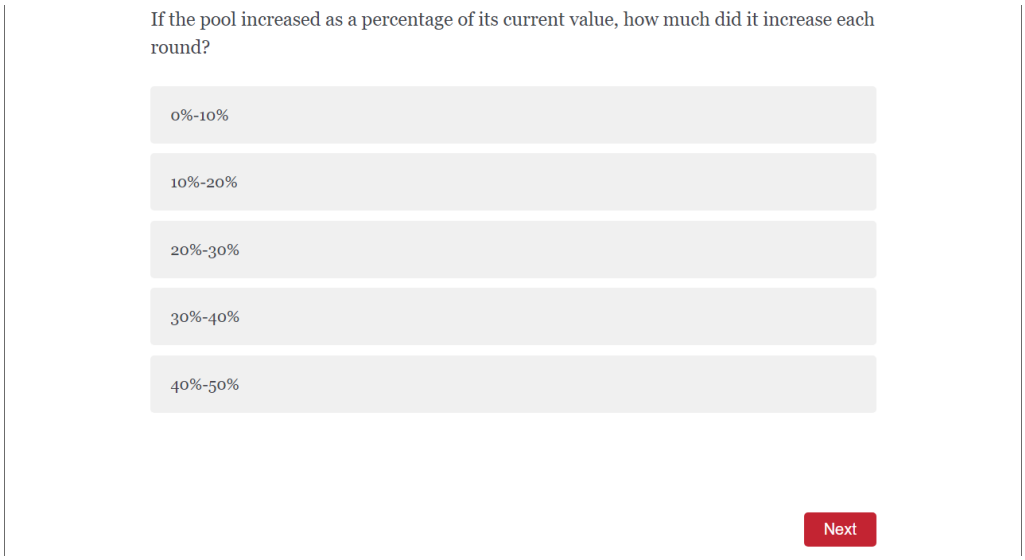
We asked participants about their understanding of the resource replenished in the game they had just played.



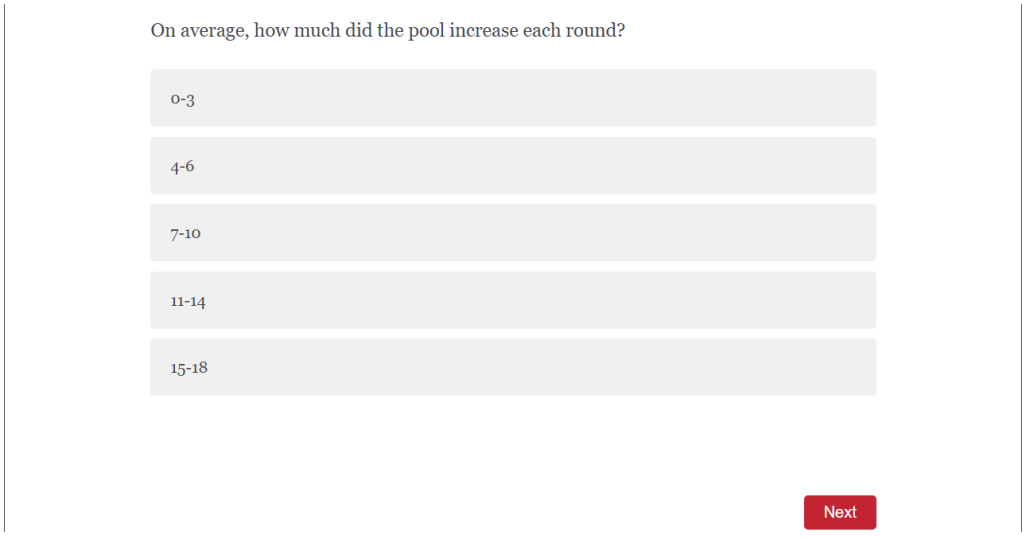

Depending on how a participant answered the question below, they may have been asked one additional question after this one.



If a participant answered the first question *'The value of the pool was increased randomly, as a percentage of its current value,'* they were then asked this question:




If a participant answered the first question *'The value of the pool increased randomly, but by a fixed average amount,'* they were then asked this question:




Otherwise, the participant would only be asked the first question and then move on to the next part of the survey.

**Individual characteristic measures:**

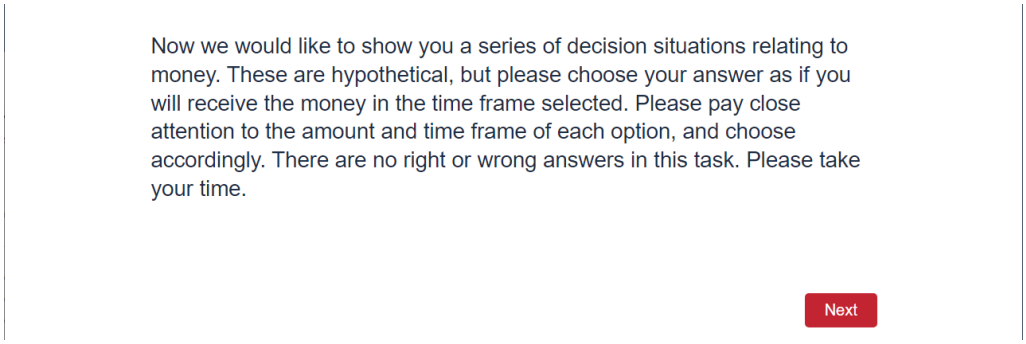
We then asked participants to complete some questionnaires to measure their individual characteristics. Data for this experiment was collected in two waves. In the first wave, 200 participants completed the (i) $ED_{50}$ (Cox & Dallery, 2016), (ii) GHQ-12 (Goldberg et al., 1997), (iii) AUDIT (Reinert & Allen, 2002); and (iv) WHO-5 (Topp et al., 2015). In the second wave, 200 participants completed the elicitations for: (i) ED50 and (ii) financial literacy (OECD; Čonková, 2014).

Therefore, the procedure for the two waves differed a little for this part of the experiment. However, both waves started off this part of the experiment by completing the $ED_{50}$, a measure of delay discounting.

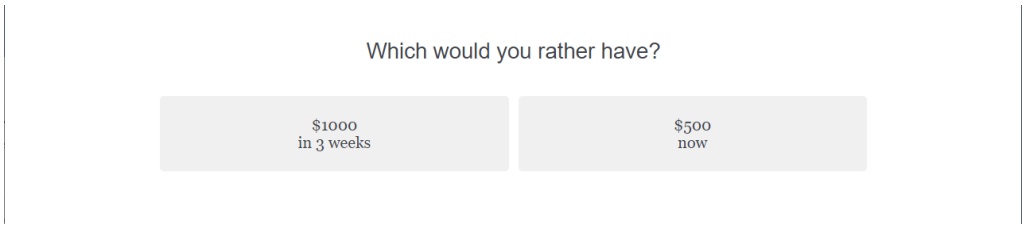
**$ED_{50}$ task:**

In the $ED_{50}$ task (Koffarnus & Bickel, 2014), participants are presented with five consecutive choices, where they indicate whether they would prefer $500 now or $1000 after some delay. If the participant chooses the immediate sum of $500 in one round, the delay for the $1000 sum is decreased for the next choice. Likewise, if the participant chooses the delayed $1000 sum in one round, the delay is increased for the following round. By the fifth round, through adjusting the delay for the later reward according to a participant's choices, we find the point at which the participant subjectively devalues the later sum by 50%. The $ED_{50}$ score is determined by the participant's choice in the fifth round of the task. Of note, for each question, we randomized the order of the $500 and $1000 choice.

Below, we give an example play-through of the first two choices a participant might make in the task.

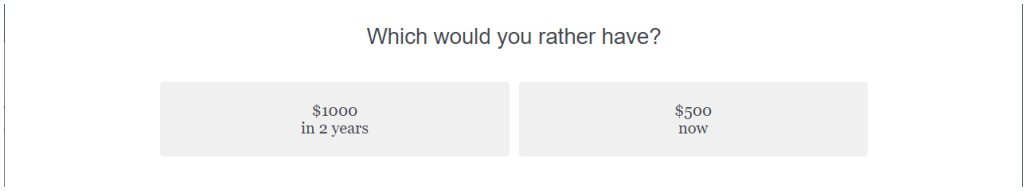



All participants started the task with the following hypothetical decision:



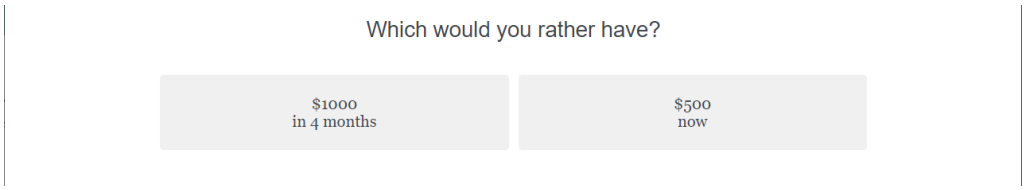

A participant may, for example, prefer the delayed sum here.


The delay for the $1000 sum is then increased for the next decision.




The participant may then prefer the immediate sum in this decision.

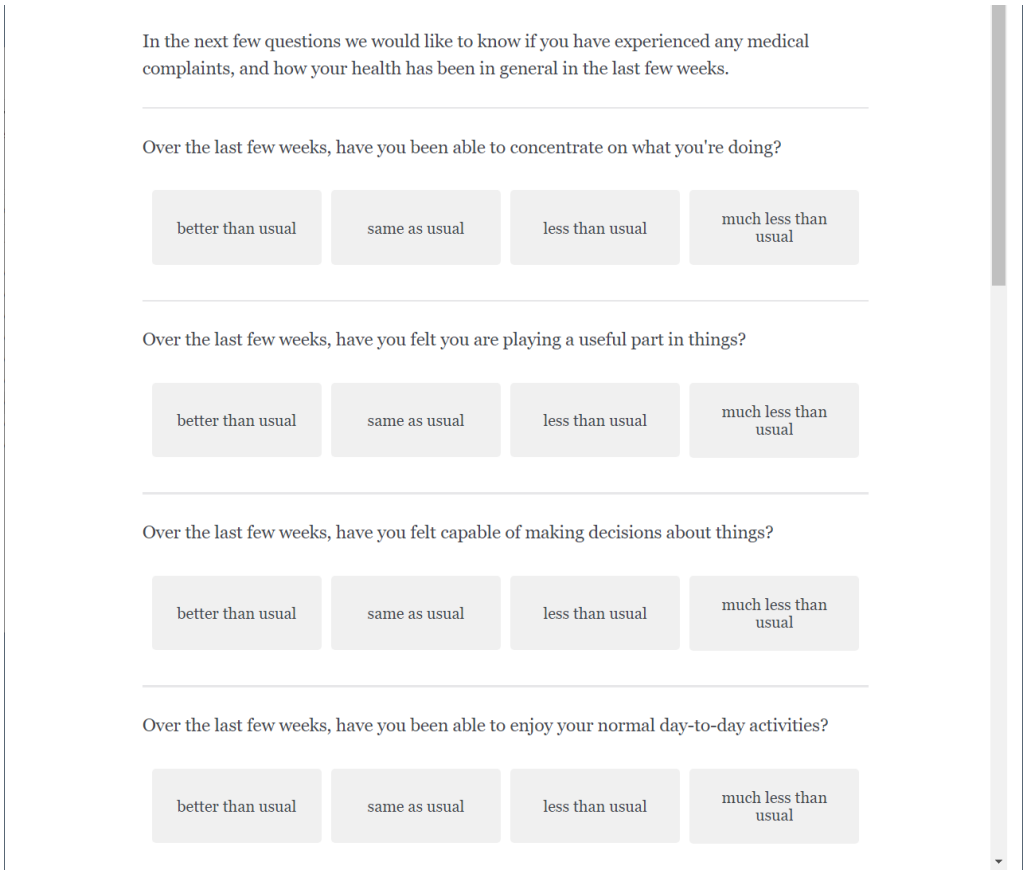

The delay for the $1000 sum is then reduced for the next round.




At this point, the two versions of the survey (used in the two waves of data collection) diverge. The following (up to the 'Game Over' end of survey message) is the procedure used for the **first wave** of data collection.

**Wave 1: General Health Questionnaire – short form version (GHQ-12)**

Here, participants completed the GHQ-12 (Goldberg et al., 1997), a short form, twelve-item version of the The General Health Questionnaire (GHQ; (Goldberg & Blackwell, 1970) developed to help identify psychological distress. Each item is scored from 0 (“better than usual”) to 3 (“much less than usual”).



Over the last few weeks, have you been able to face up to your problems?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

Over the last few weeks, all things considered have you been feeling reasonably happy?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

Over the last few weeks, have you lost much sleep because of worry?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

Over the last few weeks, have you felt constantly under strain?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

Over the last few weeks, have you been feeling unhappy and depressed?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

Over the last few weeks, have you been losing confidence in yourself?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

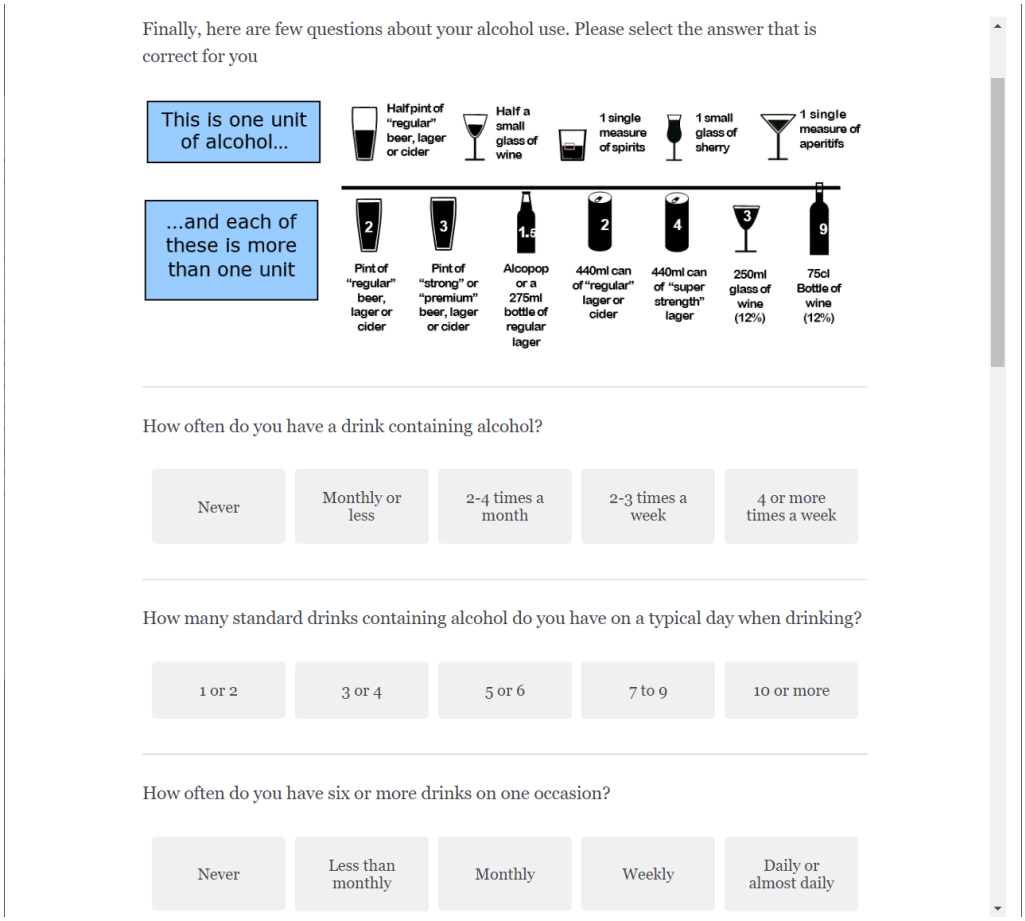
Over the last few weeks, have you been thinking of yourself as a worthless person?

| better than usual | same as usual | less than usual | much less than usual |
|---|---|---|---|

Next

**Wave 1: Alcohol Use Disorders Identification Test (AUDIT):**

The AUDIT is a 10-item questionnaire to assess harmful alcohol use (Saunders et al., 1993). All items are scored from 0 – 4. The final two items are scored 0 for 'No,' 2 for 'Yes, but not in the past year,' and 4 for 'Yes, during the past year.'



During the past year, how often have you found that you were not able to stop drinking once you had started?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|

During the past year, how often have you failed to do what was normally expected of you because of drinking?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|

During the past year, how often have you needed a drink in the morning to get yourself going after a heavy drinking session?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|

During the past year, how often have you had a feeling of guilt or remorse after drinking?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|

During the past year, have you been unable to remember what happened the night before because you had been drinking?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|

Have you or someone else been injured as a result of your drinking?

| No | Yes, but not in the past year | Yes, during the past year |
|---|---|---|

Has a relative or friend, doctor or other health worker been concerned about your drinking or suggested you cut down?

| No | Yes, but not in the past year | Yes, during the past year |
|---|---|---|

Next

**Wave 1: World Health Organization Five Well-Being Index (WHO-5)**:

Here, participants completed the WHO-5 (Topp et al., 2015), a short-report measure of subjective well-being. Items are scored from 0 (“All of the time”) to 5 (“At no time”).

**WHO (Five) Well-Being Index**

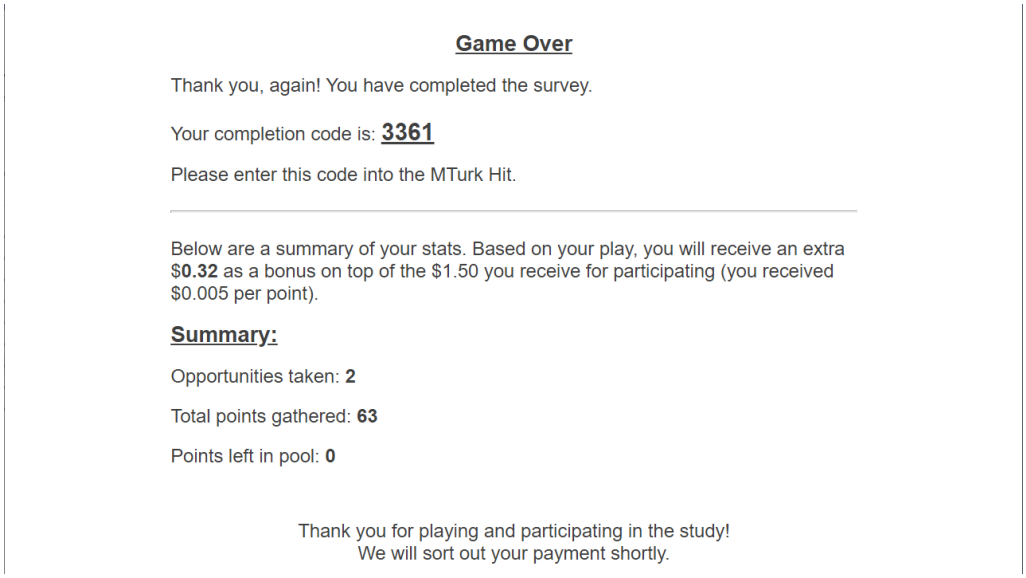
Please indicate for each of the five statements which is closest to how you have been feeling over the last two weeks.

| | All of the time | Most of the time | More than half of the time | Less than half of the time | Some of the time | At no time |
|---|---|---|---|---|---|---|
| I have felt cheerful and in good spirits | ○ | ○ | ○ | ○ | ○ | ○ |
| I have felt calm and relaxed | ○ | ○ | ○ | ○ | ○ | ○ |
| I have felt active and vigorous | ○ | ○ | ○ | ○ | ○ | ○ |
| I woke up feeling fresh and rested | ○ | ○ | ○ | ○ | ○ | ○ |
| My daily life has been filled with things that interest me | ○ | ○ | ○ | ○ | ○ | ○ |

Next

**Wave 1: End of survey page:**

Finally, the participants were thanked for taking part and shown a summary of their game stats and money earned.



**Game Over**

Thank you, again! You have completed the survey.

Your completion code is: **3361**

Please enter this code into the MTurk Hit.

---

Below are a summary of your stats. Based on your play, you will receive an extra $**0.32** as a bonus on top of the $1.50 you receive for participating (you received $0.005 per point).

**Summary:**

Opportunities taken: **2**

Total points gathered: **63**

Points left in pool: **0**

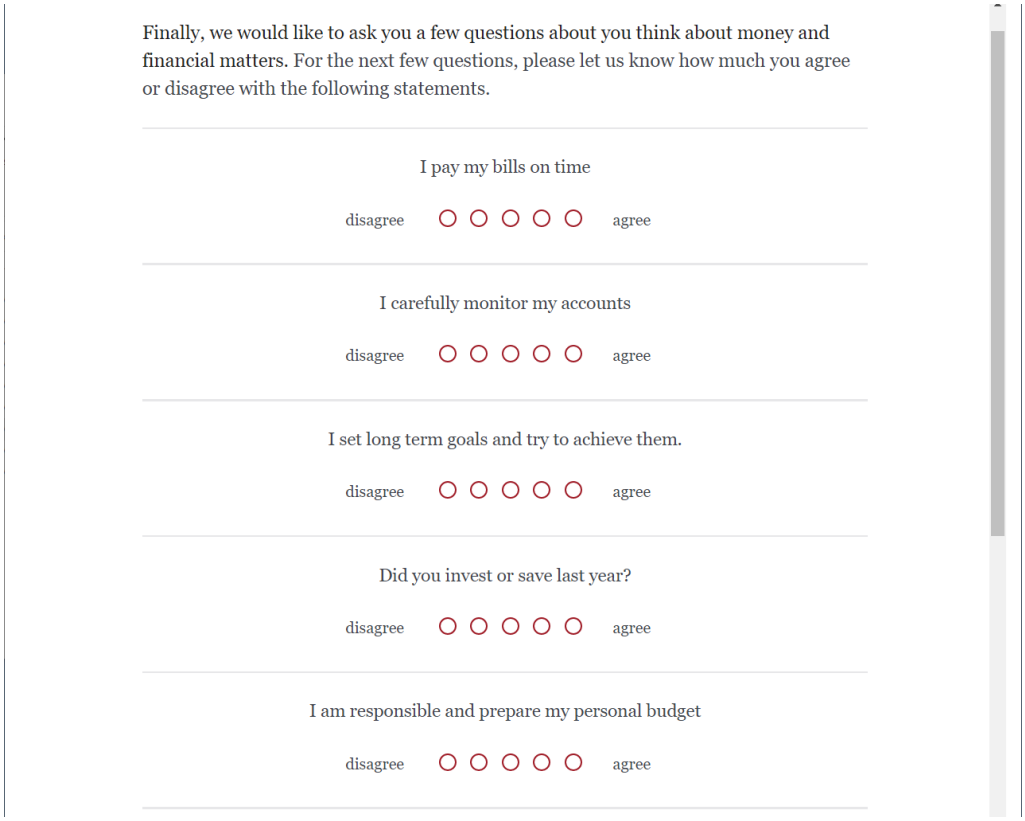
Thank you for playing and participating in the study!
We will sort out your payment shortly.

See the following pages for the procedure in wave 2.

After the $ED_{50}$, the two versions of the survey (used in the two waves of data collection) diverge. The following is the rest of the procedure for the **second wave** of data collection.

**Wave 2: OECD Financial Literacy Survey:**

Instead of completing the GHQ-12, AUDIT, and WHO-5 questionnaires, participants in the second wave of data collection completed a short form version of the Organisation for Economic Co-operation and Development (OECD) financial literacy survey (Čonková, 2014). Items were scored from 1 ("disagree") to 5 ("agree").



I find it more satisfying to spend money than to save it for the long term

disagree ○ ○ ○ ○ ○ agree

I tend to live for today and let tomorrow take care of itself

disagree ○ ○ ○ ○ ○ agree

Money is there to be spent

disagree ○ ○ ○ ○ ○ agree

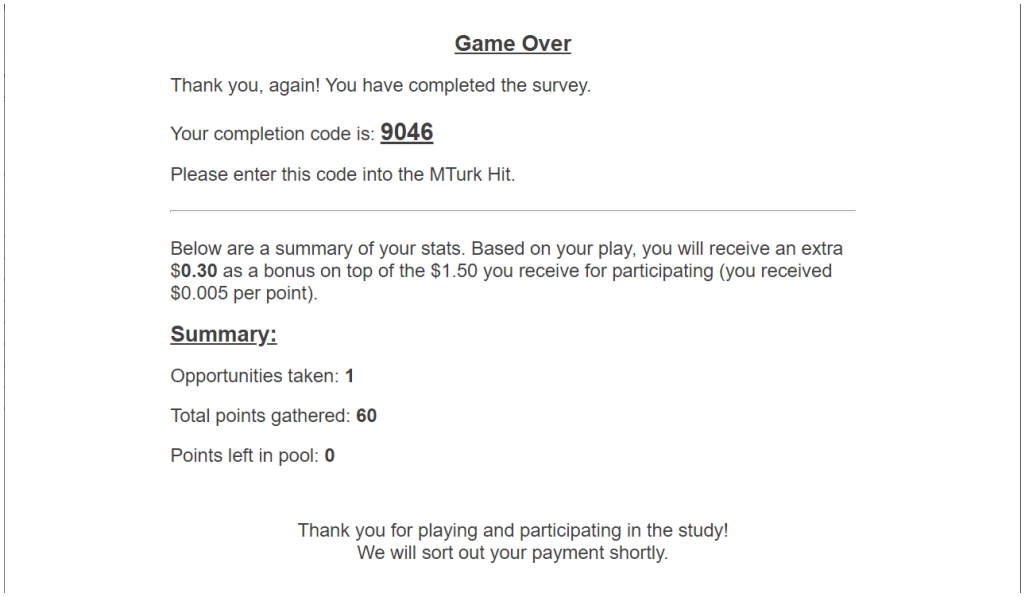
I choose financial products after gathering adequate information

disagree ○ ○ ○ ○ ○ agree

Next

**Wave 2: End of survey page:**

Finally, just as in the first wave of data collection, the participants were thanked for taking part and shown a summary of their game stats and money earned.



**Game Over**

Thank you, again! You have completed the survey.

Your completion code is: **9046**

Please enter this code into the MTurk Hit.

---

Below are a summary of your stats. Based on your play, you will receive an extra $**0.30** as a bonus on top of the $1.50 you receive for participating (you received $0.005 per point).

**Summary:**

Opportunities taken: **1**

Total points gathered: **60**

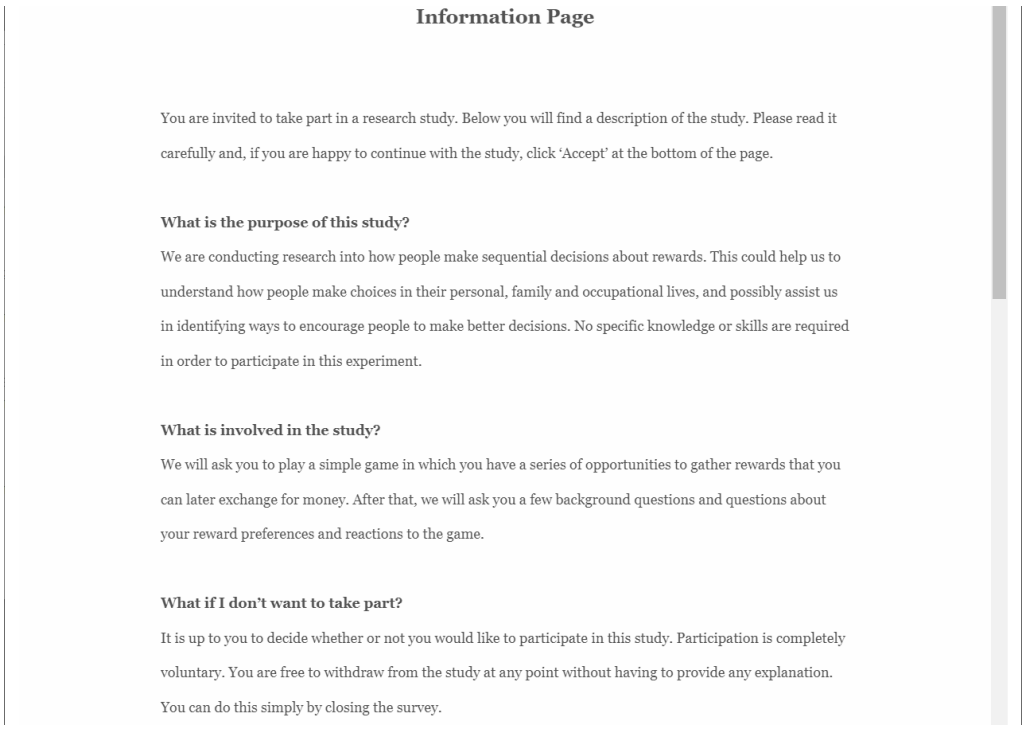
Points left in pool: **0**

Thank you for playing and participating in the study!
We will sort out your payment shortly.

***Experiment 2:***

**Participant information page and consent form:**

Prior to completing the protocol, the participant needed to consent to participate. To do this, each participant was shown the below Information Page. At the end of the page, they agreed to several bullet points (e.g., that they knew they could quit at any point by closing the experiment). The participant agreed to the consent form by clicking 'Accept' at the bottom of the page.



**Information Page**

You are invited to take part in a research study. Below you will find a description of the study. Please read it carefully and, if you are happy to continue with the study, click 'Accept' at the bottom of the page.

**What is the purpose of this study?**

We are conducting research into how people make sequential decisions about rewards. This could help us to understand how people make choices in their personal, family and occupational lives, and possibly assist us in identifying ways to encourage people to make better decisions. No specific knowledge or skills are required in order to participate in this experiment.

**What is involved in the study?**

We will ask you to play a simple game in which you have a series of opportunities to gather rewards that you can later exchange for money. After that, we will ask you a few background questions and questions about your reward preferences and reactions to the game.

**What if I don't want to take part?**

It is up to you to decide whether or not you would like to participate in this study. Participation is completely voluntary. You are free to withdraw from the study at any point without having to provide any explanation. You can do this simply by closing the survey.

**What will happen to my data?**

We may use the results to write an academic paper. This and any other publications will not identify you individually. All data collected will be treated in the strictest confidence. The data will be stored securely for 7 years. If you choose to withdraw from the study and your data is identifiable to the research team, you have the right to request that your data is not used and destroyed (as long as data analysis has not begun). Learning about how people manage resources could help us to find ways to assist vulnerable groups and, perhaps, develop sustainability policies.

**Who do I contact for further information?**

If you have any questions or want to leave the study, please email: p.rauwolf@bangor.ac.uk. We will do our best to answer your queries quickly.

**Is there anything else I should know?**

Since this study is considering individual responses, we can only let you complete the survey once. If you take the survey more than once, you will only get paid for the first study. If you choose to leave the study at any point, all of your data will be destroyed.

**Who is running the study?**

This survey is run by the School of Psychology (Bangor University).

The study has been approved by the university's Psychology Research Ethics Committee (Study No: 2017-16211).

Dr Paul Rauwolf

Professor Robert D Rogers

School of Psychology

Brigantia Building

Bangor University

LL57 2AS, UK

E-mail: p.rauwolf@bangor.ac.uk

**Consent Form:**

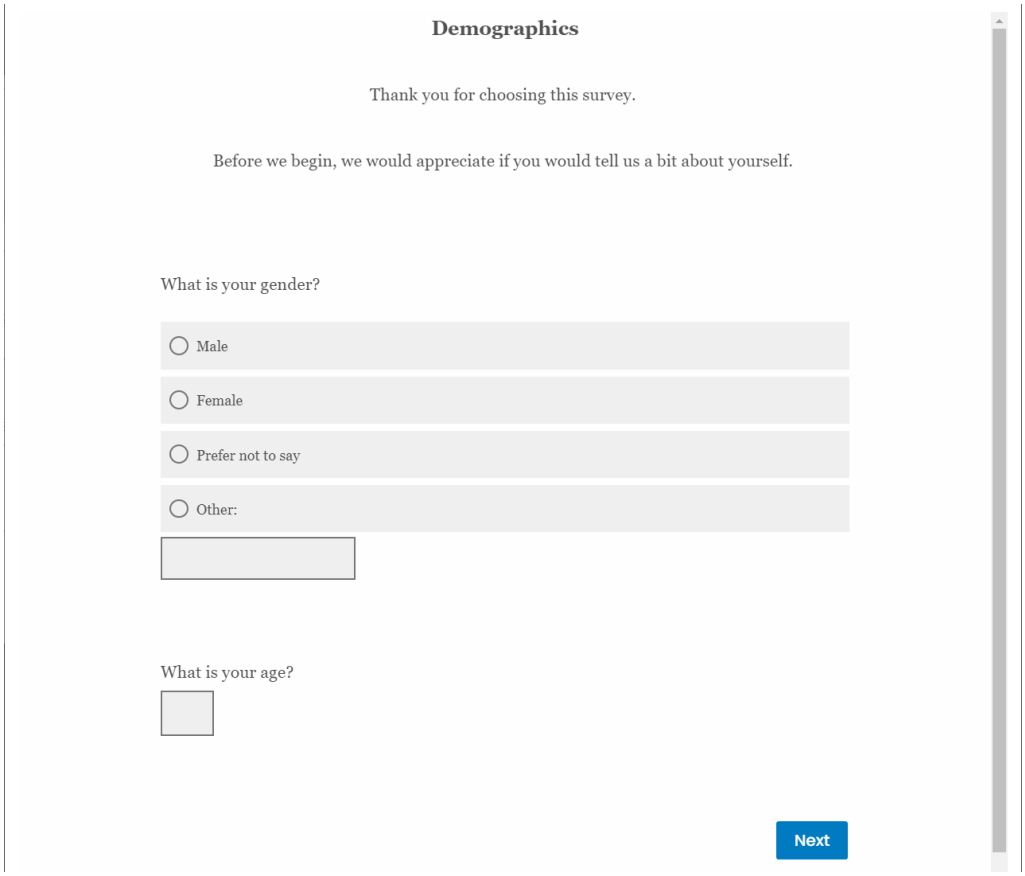
By clicking 'Accept' below, you agree to the following:

- I have read the information above and understand what is involved in the study.
- I consent for my anonymised responses to be used in academic publications.
- I understand that my participation is voluntary, that I am free to leave the study at any time, and that if I do so, my data will be removed from the study
- I understand that I will only get paid for completing the questionnaire once.
- I understand that Bangor University may wish to audit anonymised data as part of research governance.
- I agree to participate in the study.

Accept

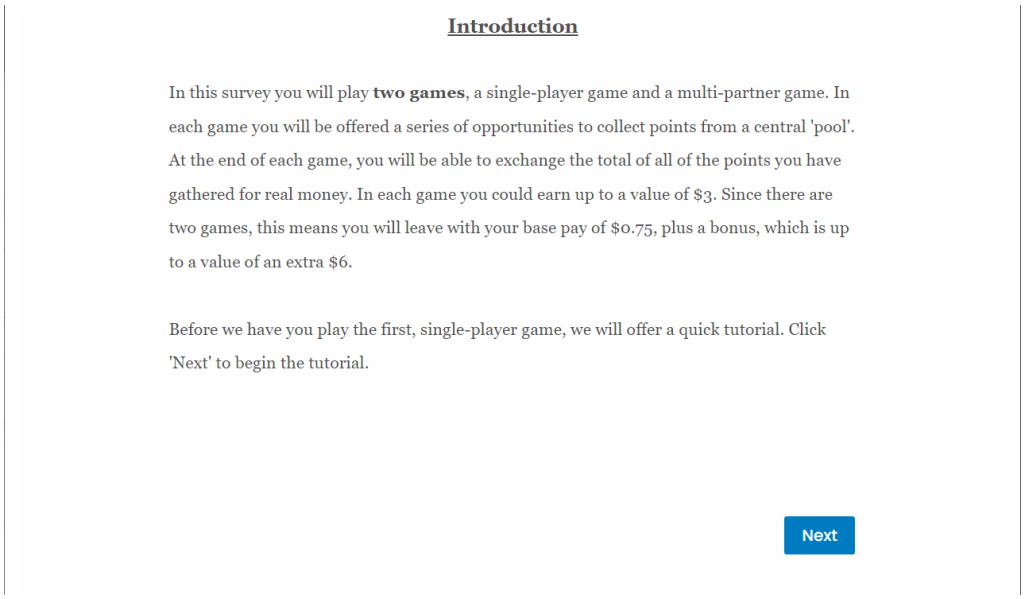
**Participant demographic information:**

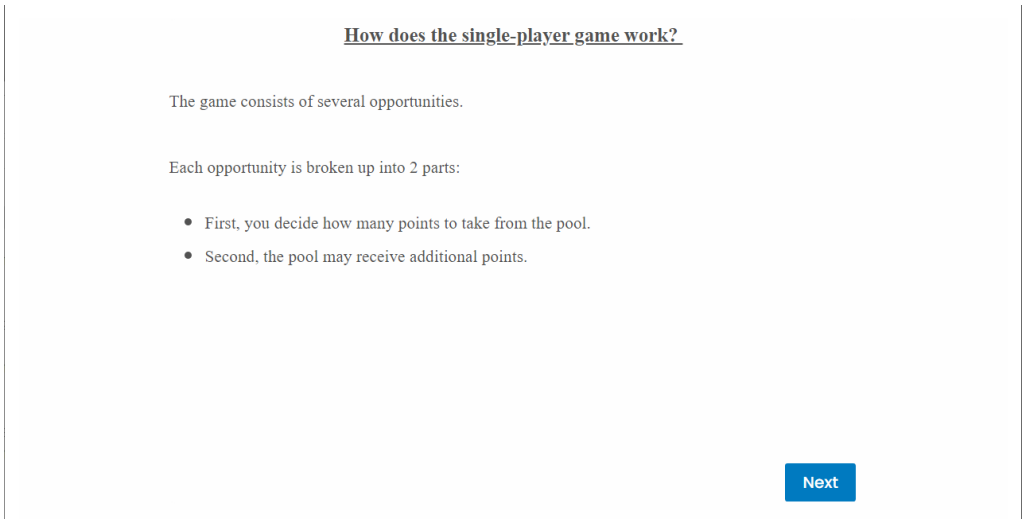
Here, we asked participants a couple of demographic questions (gender and age).



**Instructions:**

Before participants played the game, we offered a tutorial about how the game works and what they were expected to do. We did not tell the participants the replenishment rate, maximum number of rounds, or monetary value of each reward earned. Participants were only told that they could earn a maximum of $3 in each game (participants also played a multi-player version of the game, but this is beyond the scope of this paper).



**Training**

Below is what you will see when you play the game. When you're ready, click the next button and we'll explain what everything means.


How many points would you like to take?

Next

The blue highlighted area represents the pool of points.

You can collect points from this pool.


How many points would you like to take?

Next

Each opportunity, you can choose how many points you wish to take from the pool. The blue highlighted box indicates how many points you will take on this go. You will type a number into this box, and that amount will be removed from the pool and added to your total points.


How many points would you like to take?

Next

After you select the amount of points you wish to take, you will need to wait a moment while we:

1.) Gather your requested points

2.) Allow the pool to potentially increase

A red circle, like the one below, will appear around the pool whilst we complete these tasks. Usually this screen will disappear after a few seconds, but for training, we'll have you click 'Next' when you are ready.


Next

**Repeat**

After you've collected points from the pool, and the pool has been allowed to increase, you will receive another opportunity to collect points. These opportunities to collect points will continue until the game ends.

Next

## When does the game end?

The game ends when either:

1.) the pool reaches zero, or
2.) when you've had a number of opportunities to collect points.

Next

## How much money do I win?

The amount of bonus money you win is based on the total number of points that you gather throughout each game. More points equals more money.

You could earn up to $3 in bonus cash.

Next

## What happens if the pool goes to zero quickly?

To start, if you deplete the pool quickly, then you will miss out on potential points, and thus money!

Second, if the pool is depleted too quickly, then you will be penalized by having to wait a specific period of time before continuing. You will have to wait up to **5 minutes** before you can continue the survey. After the game you will see a screen like the one below. The 'Next' button will only become available after the counter hits zero. The more rounds you make the pool last, the less time you have to wait.

---

**Since you depleted the pool quickly, you must wait before proceeding.**

**When the time hits zero, click the 'Next' button to continue.**

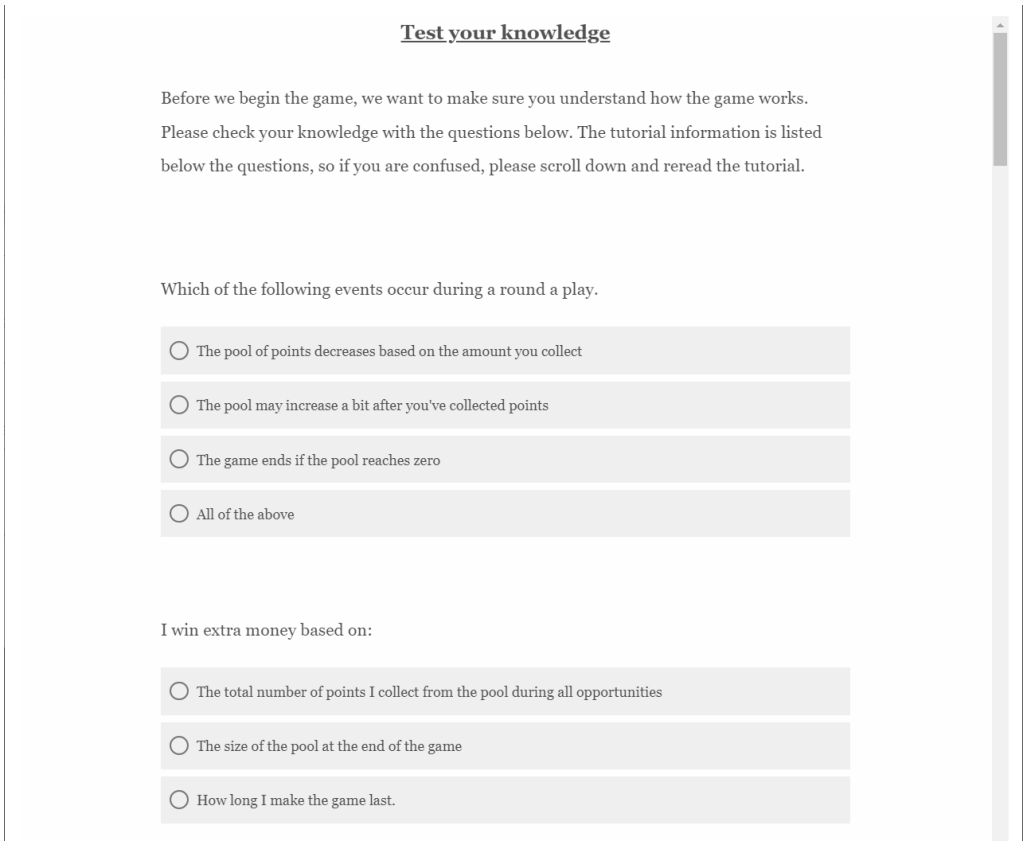
**The rest of the survey will become available in:**

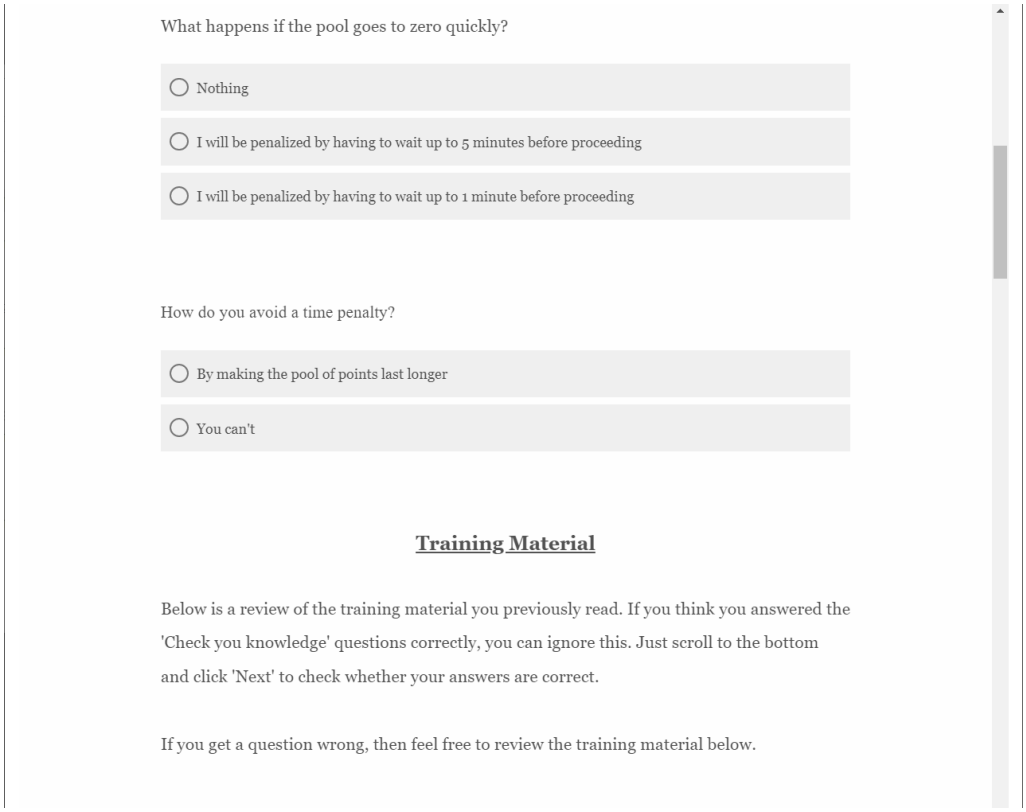
**04:37**

Next

**Questions to assess participant understanding:**

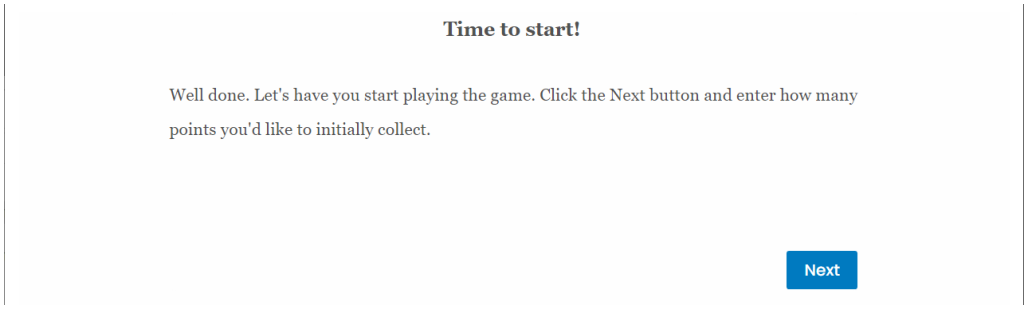
Here, we asked participants four multiple-choice questions to assess their understanding of the game. Participants could not continue past this page until they had selected the correct answer for each of these questions. This page also contained all the instructions previously given to the participant, to revise again if necessary. We haven't included screenshots of this, as the instructions are identical to those shown above.



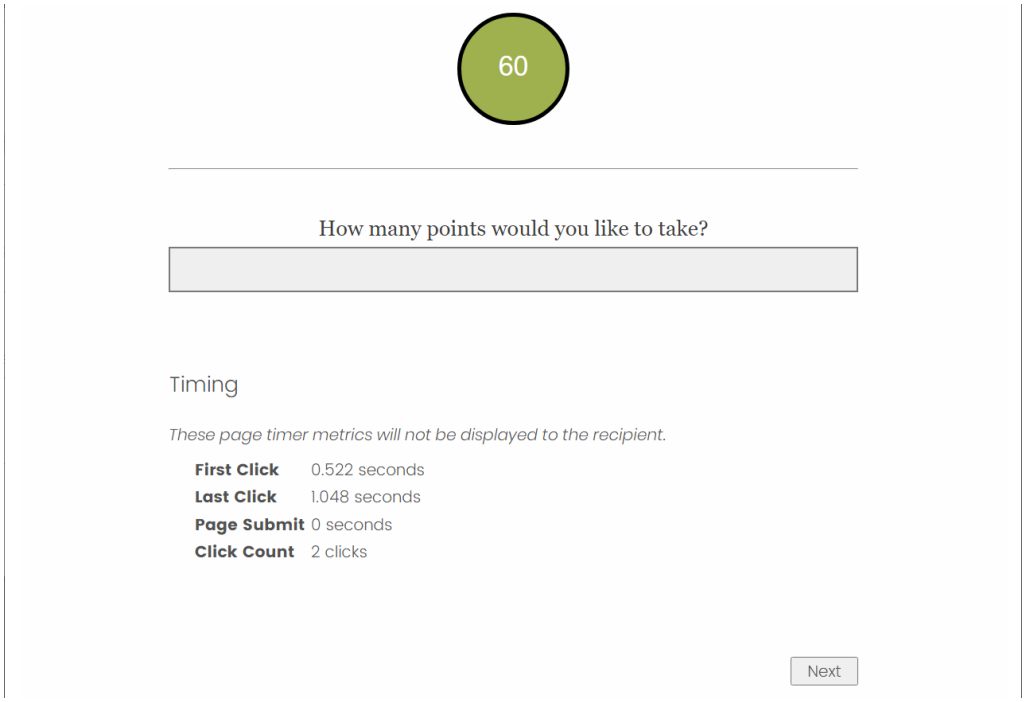



**Playing the game:**

Once they had answered the ‘Test your knowledge’ questions correctly, participants played the game. In these screenshots, we show an example of a participant who lasted two rounds in the game.

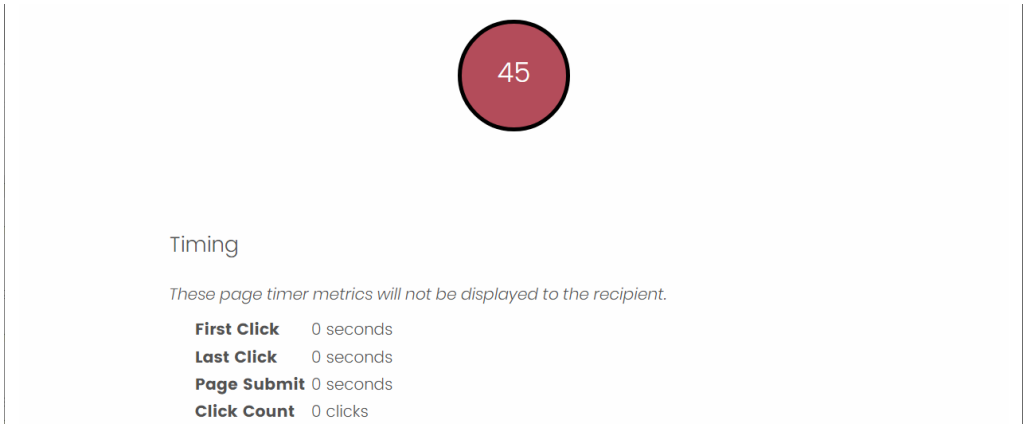


The resource always started at its maximum capacity of 60. Participants typed the number of rewards they wanted to harvest into the grey box, and then clicked ‘Next’ to harvest these rewards.

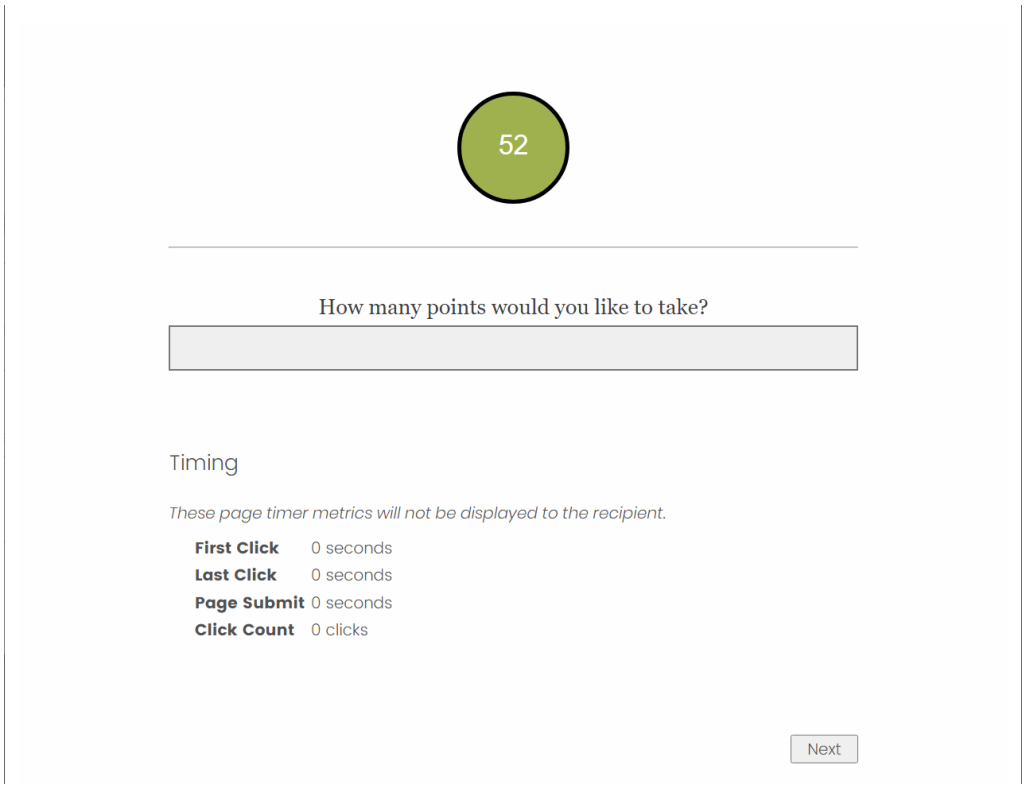


As an example, a participant might take 15 rewards from the resource in the first round.

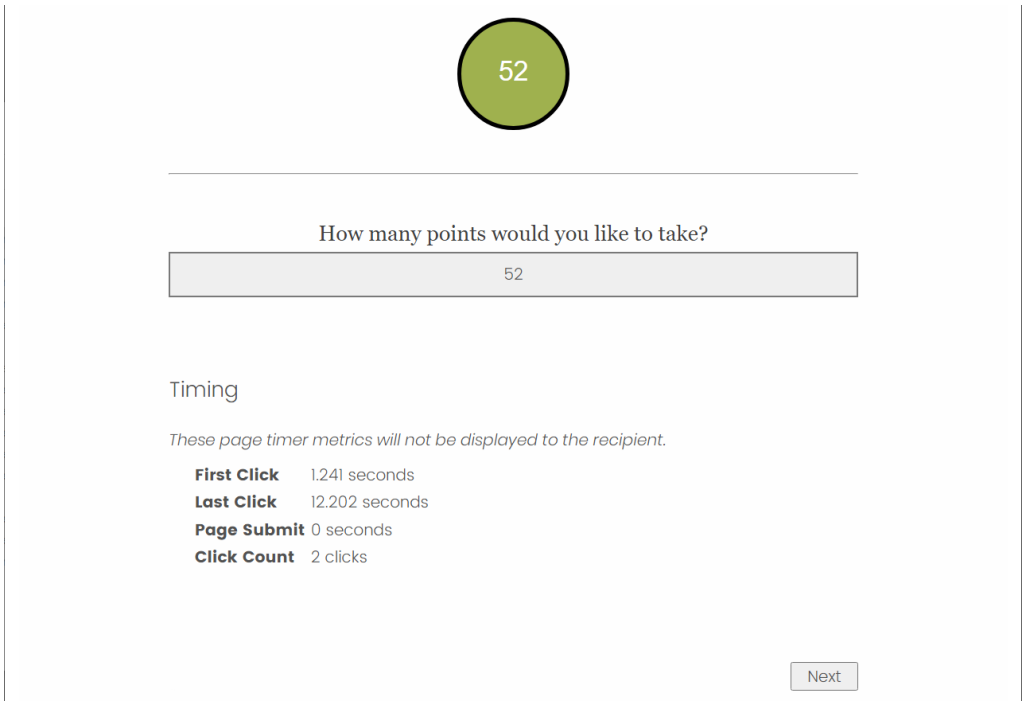

Once the participant clicked ‘Next’, they would see this page for a couple of seconds.



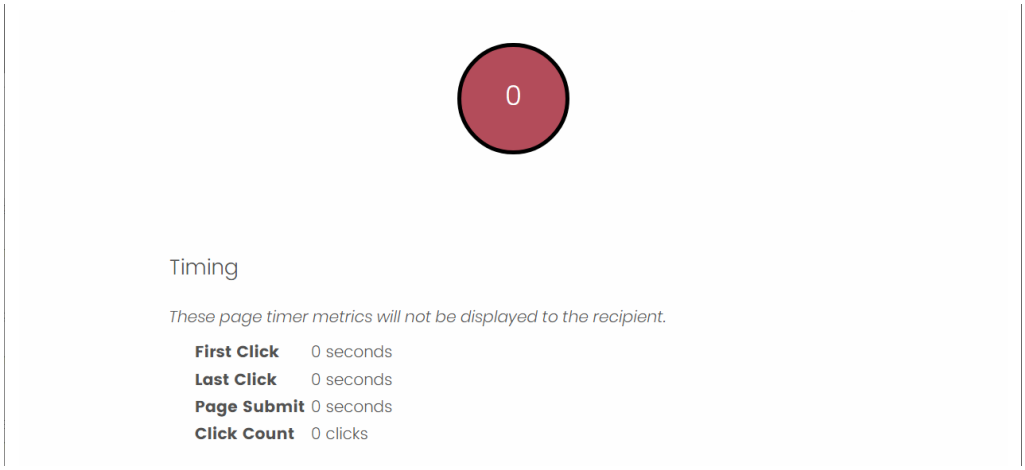
The resource would then replenish by around 15%.



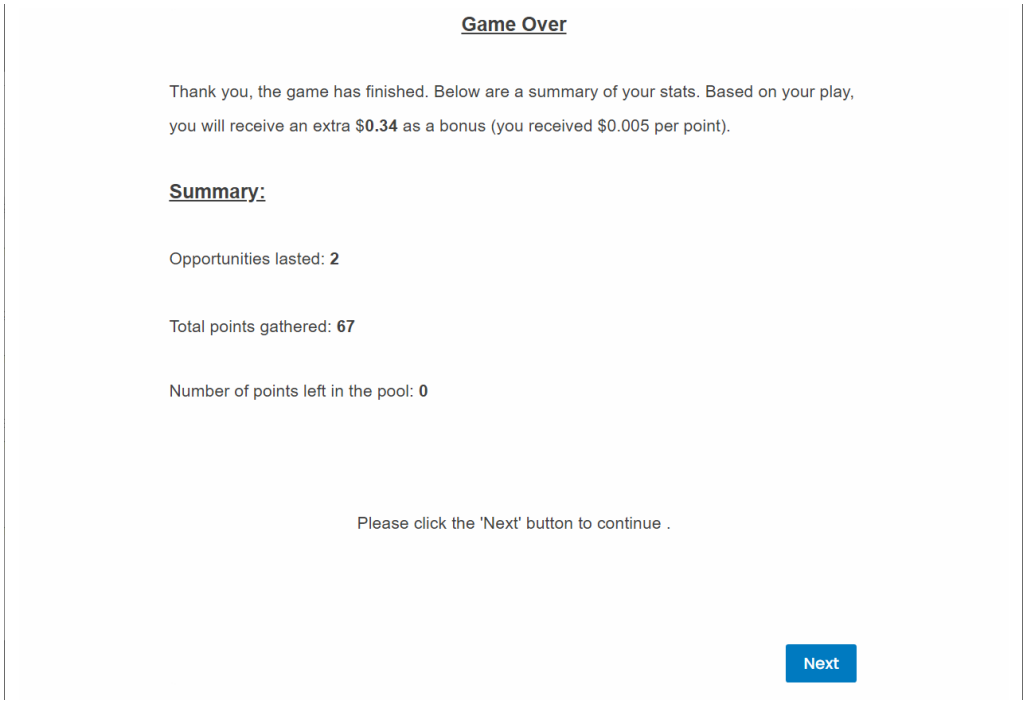
Perhaps, the participant might then choose to harvest the full amount of rewards contained in the pool.



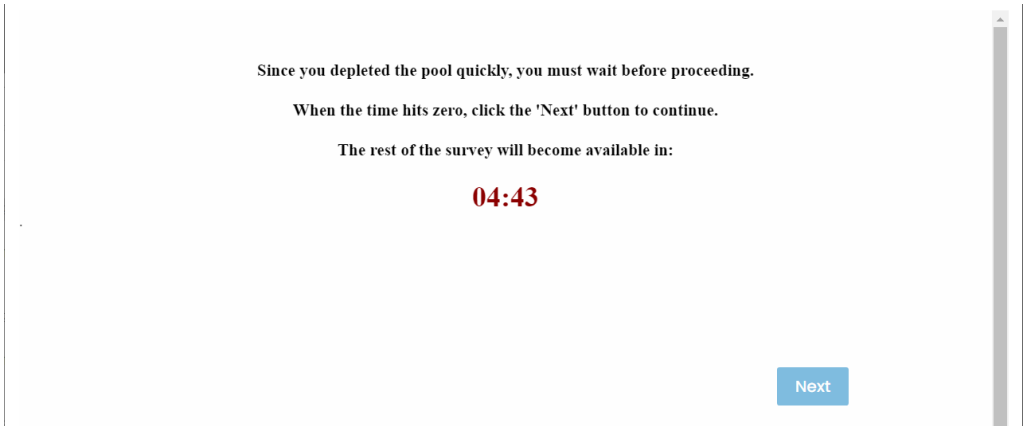

The resource would then be depleted to zero and would replenish no more.



Once the game finished, participants saw this page, with a summary of how they played and how much money they earned.

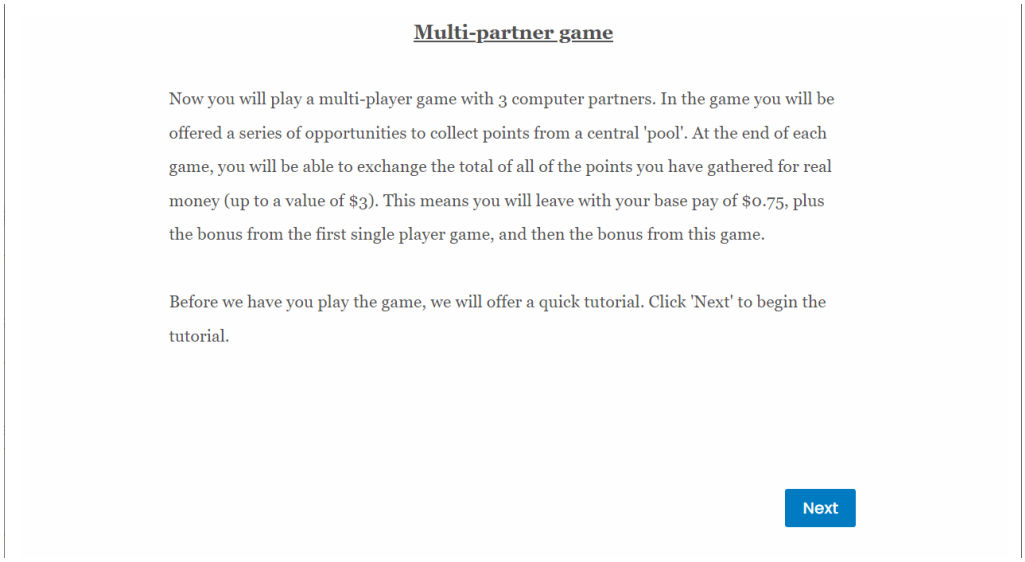



As the participant in our example finished the game before round 50, they would have to wait for a time penalty before they could continue.



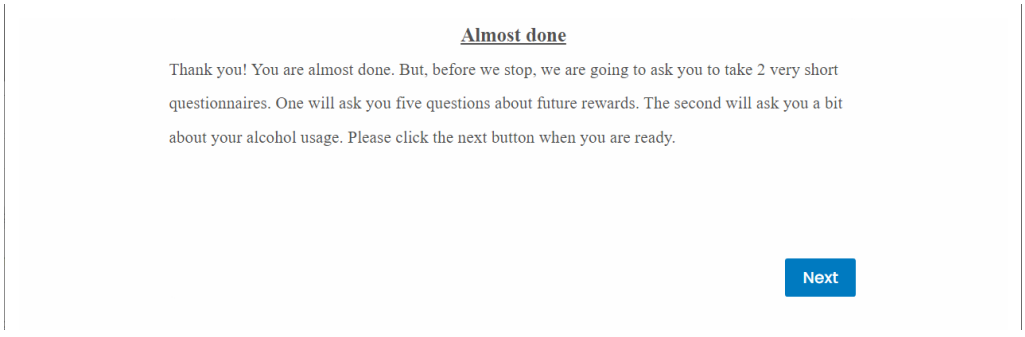
**Multi-partner game:**

In Experiment 2, participants also played a multi-player version of the game. However, this is beyond the scope of this paper, and so we do not include further screenshots of this game here.




**Questionnaires:**

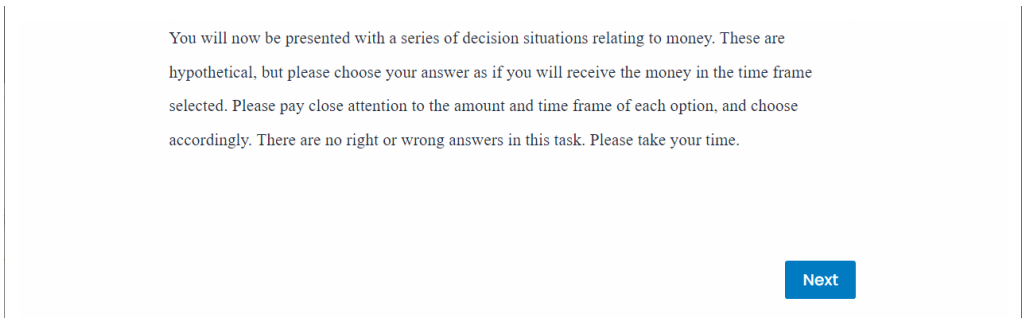
After finishing the multi-partner game, participants were asked to complete two short questionnaires: the $ED_{50}$ task and the Alcohol Use Disorders Identification Test.



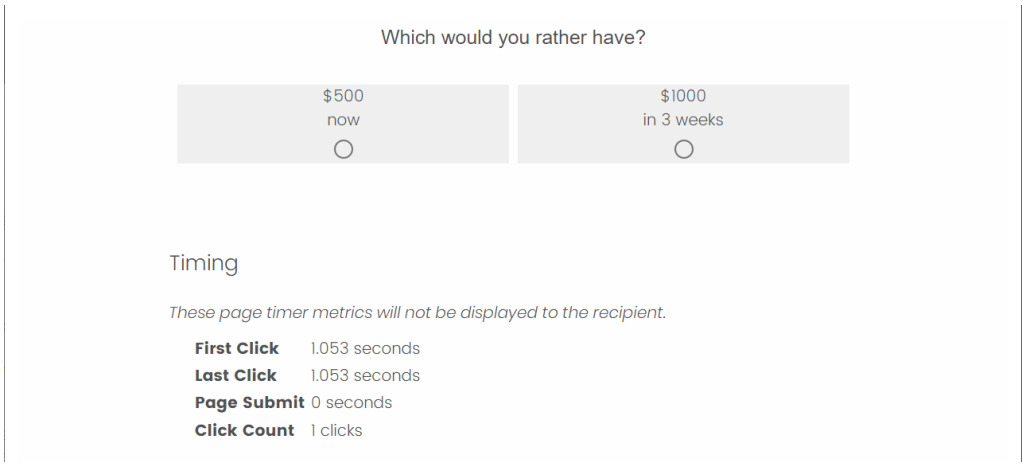
**$ED_{50}$ task:**

In the $ED_{50}$ task (Koffarnus & Bickel, 2014), participants are presented with five consecutive choices, where they indicate whether they would prefer $500 now or $1000 after some delay. If the participant chooses the immediate sum of $500 in one round, the delay for the $1000 sum is decreased for the next choice. Likewise, if the participant chooses the delayed $1000 sum in one round, the delay is increased for the following round. By the fifth round, through adjusting the delay for the later reward according to a participant's choices, we find the point at which the participant subjectively devalues the later sum by 50%. The $ED_{50}$ score is determined by the participant's choice in the fifth round of the task. Of note, for each question, we randomized the order of the $500 and $1000 choice.

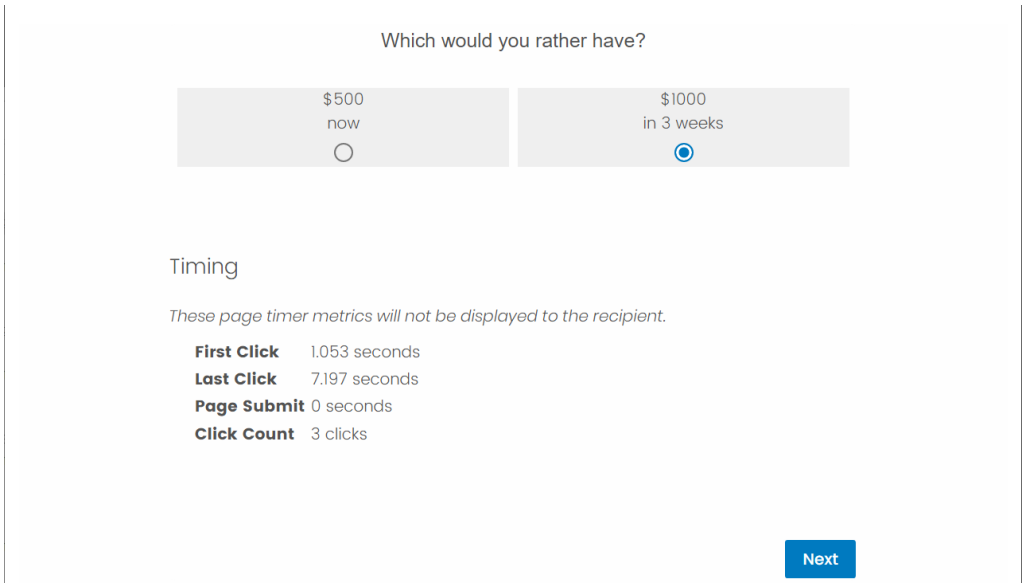
Below, we give an example play-through of the first two choices a participant might make in the task.



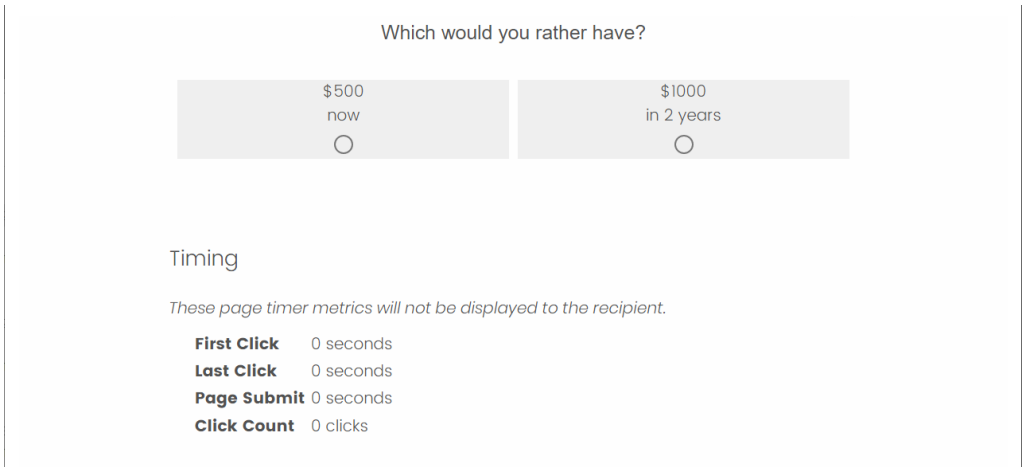
All participants started the task with the following hypothetical decision:



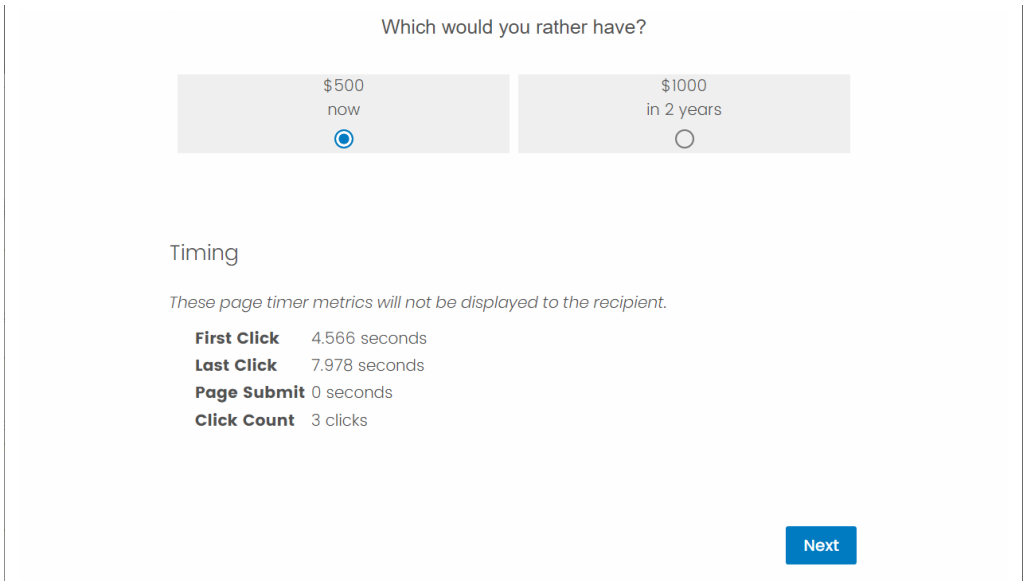

A participant may, for example, prefer the delayed sum here.



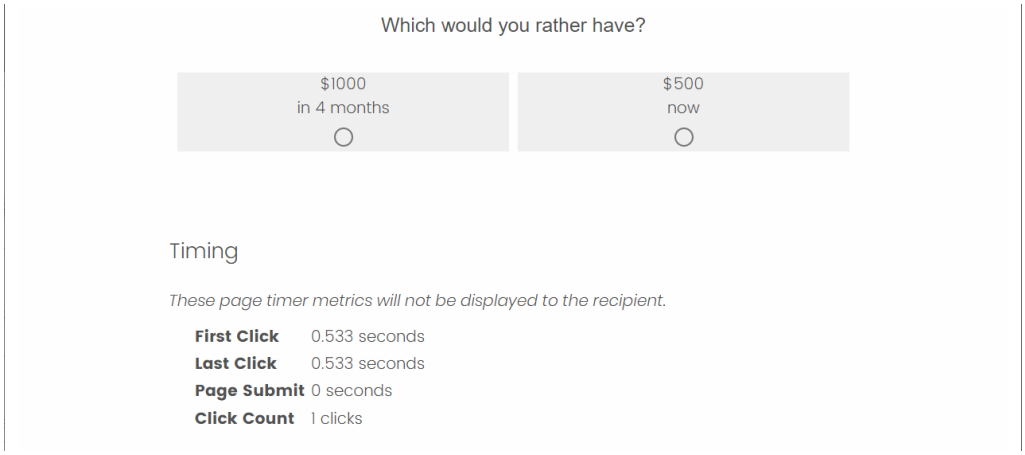
The delay for the $1000 sum is then increased for the next decision.




The participant may then prefer the immediate sum in this decision.

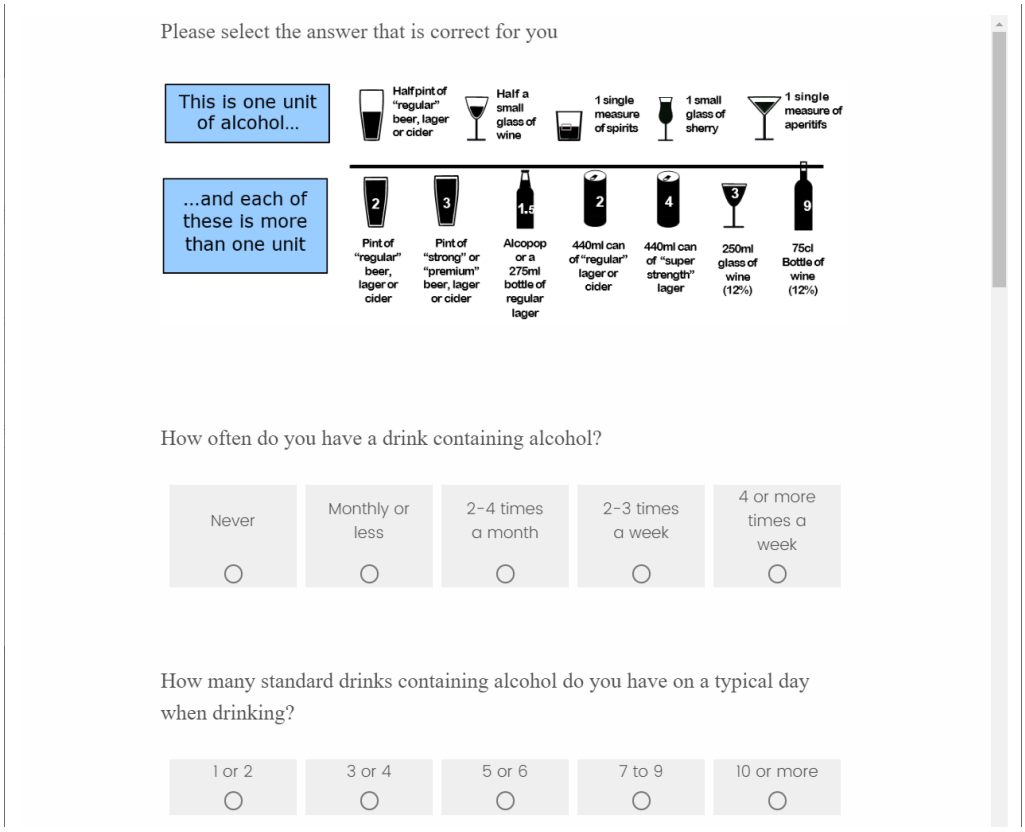



The delay for the $1000 sum is then reduced for the next round.



**Alcohol Use Disorders Identification Test (AUDIT):**

The AUDIT is a 10-item questionnaire to assess harmful alcohol use (Saunders et al., 1993). All items are scored from 0 – 4. The final two items are scored 0 for 'No,' 2 for 'Yes, but not in the past year,' and 4 for 'Yes, during the past year.'



How often do you have six or more drinks on one occasion?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

During the past year, how often have you found that you were not able to stop drinking once you had started?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

During the past year, how often have you failed to do what was normally expected of you because of drinking?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

During the past year, how often have you needed a drink in the morning to get yourself going after a heavy drinking session?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

During the past year, how often have you had a feeling of guilt or remorse after drinking?

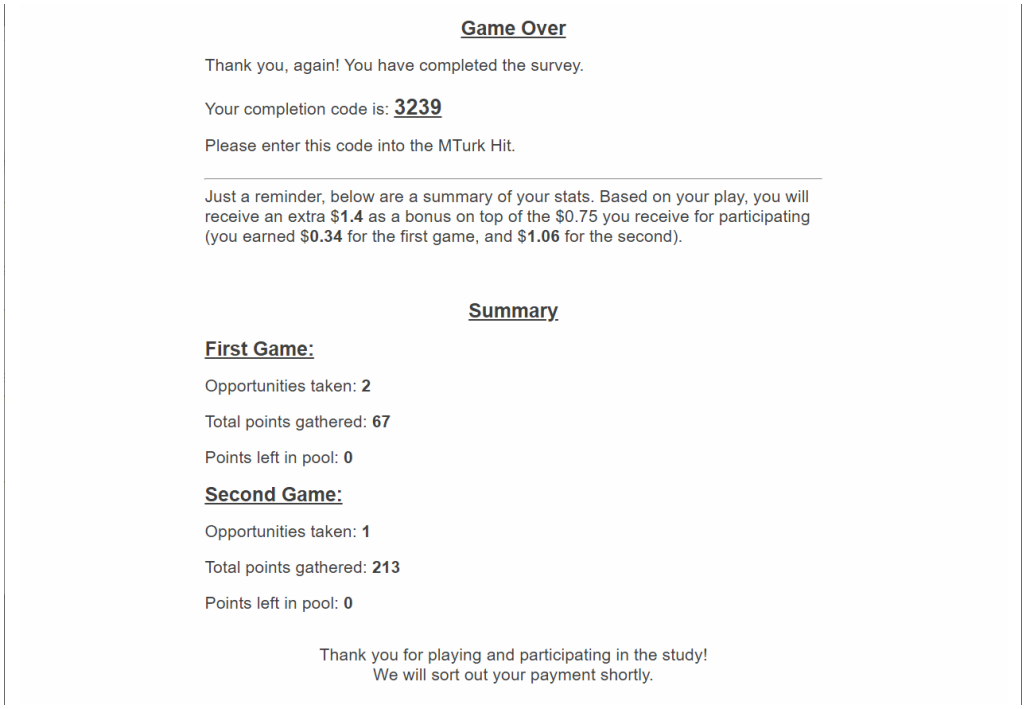
| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

During the past year, have you been unable to remember what happened the night before because you had been drinking?

| Never | Less than monthly | Monthly | Weekly | Daily or almost daily |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |


**End of survey page:**

Finally, the participants were thanked for taking part and shown a summary of their game stats and money earned.



## Supplemental Material B – Calculating the optimal policy of the resource management game

In the resource management game, the participants' objective was to harvest as many points as possible over the duration of the game. As participants in our experiment did not know the duration of the game, they had to maximise this cumulative reward over an indefinite time period. Thus, a sensible strategy would be to take modest harvests from the resource, allowing the resource to replenish to its maximum level each round and maximising the rewards available in future rounds. However, the stochastic nature of the resource's replenishment rate added an extra layer of complexity to participants' harvest decisions, increasing uncertainty about potential future rewards in the game. The optimal strategy for the game is, therefore, not immediately obvious.

To determine the optimal strategy, we modelled decisions in the game using a Markov Decision Process (MDP; Bellman, 1957a; Sutton & Barto, 1998). A MDP is a mathematical framework used to model Markov sequential decision-making problems with stochastic elements, such as the resource management game. A MDP represents a game as a set of states, actions, rewards, and transition probabilities. Using this framework for the resource management game, the states correspond to the possible levels of the resource, the actions correspond to the possible harvest amounts, the rewards correspond to the points gained from each harvest, and the transition probabilities correspond to the probabilities of the resource replenishing to each possible resource level, based on its current level and the replenishment rate.

More specifically, in the case of the resource management game, there are 61 possible states, since the resource can hold a value of any integer in the range: [0, 60]. If the current value of the resource is defined as $v$, then, at any given round, the action set available to a participant is defined as an integer in the range: [0, $v$]. The participant can harvest any value of the resource between zero and the current value of the resource. The reward received for each action is defined as the amount harvested by that action. Finally, the transition probability represents the likelihood of transitioning to a specific state ($s'$) given that a participant was in a state ($s$) and took the action to harvest a certain amount ($a$): $P(s' \mid s, a)$. For example, in one round of play, if the resource contained 60 points (its current state: $s$), and the participant harvested 20 points (the action: $a$), the participant would receive 20 points (the reward), and the resource would be depleted to 40 points. Before the next round, the resource would replenish by some amount and transition to a new state. The probability of transitioning to each of the 61 possible states is given by the transition probabilities. In this example, the probability of transitioning from 40 points to 40 points or below would be zero, as the resource in our game always replenished by at least 1 point unless it had been depleted to zero. As the replenishment rate was taken from a Gaussian distribution with mean = 15%, the most probable new state would be 46 points (40 x 1.15 = 46).

By considering all possible states, actions, and their corresponding transition probabilities, we can use dynamic programming to determine the optimal policy, which specifies the action to take in each state that maximizes cumulative rewards (Bellman, 1957b). We can do this for the resource management game whether we model the game as a finite horizon problem, with a definitive end point, or as an infinite horizon problem, with no end point. As participants in our experiment did not know the duration of the game, to accumulate a large sum of points over the 70 rounds of the game they had to use a strategy which sustained the resource

indefinitely. Therefore, we first chose to model the game as an infinite horizon problem and used value iteration to find a policy optimised to maximise rewards for a duration much longer than the actual duration of our game.

***Value iteration***

When the resource management game is modelled as an infinite-horizon problem, the optimal policy can be determined using value iteration. The value iteration algorithm uses the Bellman equation to iteratively calculate and update the value of each state, considering both immediate rewards and the expected cumulative rewards of future states (Puterman, 1994). An important parameter in this calculation is the discount rate, γ, which determines the extent to which the policy is optimised for immediate versus long-term rewards. γ can be any value between 0 and 1, and as γ approaches 1, the algorithm discounts future rewards less strongly and therefore generates an optimal policy that is more focused on long-term outcomes (Sutton & Barto, 1998). We used the *mdp_value_iteration* function in the *MDPtoolbox* package in R to find the optimal harvest at each possible resource value in order to maximize the expected cumulative reward in the game. We used a discount factor of γ =.99999 so that the algorithm discounted future rewards less, encouraging it to produce a policy which was optimised for long-term outcomes.

Looking at the optimal policy produced by the value iteration algorithm, long-term cumulative rewards can be maximised by applying an *Aim for 51* strategy. If the resource level is above 51 points, long-term cumulative rewards are maximised by harvesting such that the resource is depleted to 51 points (before it is replenished ready for the following round).

If the resource level has a value of 51 points or less, it is best to harvest zero resources and allow the resource to grow until it contains more than 51 points.

This strategy does make intuitive sense. As the game was played over an unknown-horizon, the most important priority was to sustain the resource close to its maximum level to maximise the expected future rewards. However, as long as this was achieved, the next most important priority was to take as many points as possible each round. Given that the resource replenished as a percentage of its current value (each round the replenishment rate was taken from a Gaussian distribution with a mean of 15% and a standard deviation of 3%), the larger the resource the more rewards would replenish (e.g. a resource of 20 would replenish 3 rewards on average, whilst a resource of 40 would replenish 6 rewards on average). However, since the resource could not grow above 60 points, it would be sub-optimal to harvest such that resource replenishment would overshoot the 60-point ceiling. For example, if the resource was at 60, harvesting 1 would only garner 1 reward and the resource would replenish to 60 with 100% likelihood. If one harvested 2, then they would receive 2 rewards, and the resource would replenish to 60, 99.994% of the time. Thus, if the resource has a value of 60, harvesting 2 is better than harvesting 1, since the participant will receive twice the reward and likely end up in the same state for the following round. In this resource management game, aiming for 51 strikes the perfect balance between harvesting as many points as possible while still allowing the resource to replenish close to its maximum level each round.

R code for creating and running the MDP can be found at:

https://osf.io/8b7av/?view_only=075259b34db4412cbf859562cf384eed

***Backward induction***

Although the duration of our resource management game was unknown to participants, the game did have a definitive duration of 70 rounds (as long as the resource wasn't depleted to zero before then). Therefore, it could be appropriate to treat the game as a finite horizon problem. This method determines the optimal policy for a player that knows the duration of the game and would therefore produce an optimal policy that achieves the upper limit of performance in the game.

We used backward induction (Puterman, 1994) to find this optimum policy. The backward induction algorithm starts at the final round of the game and finds the optimal action to take for each possible state at this last round. The algorithm then works backwards from there and considers the second-to-last round, finding the optimal action for each state given the previously determined optimal action for the last round given the transition probabilities. It continues this process of finding the optimal action for each round and state until it reaches the first round of the game, and the optimal action for each round has been determined.

Using the *mdp_finite_horizon* function in the *MDPtoolbox* package in R, we found that the optimal policy generated using backward induction was identical to that generated through value iteration for all rounds but round 70 – the final round of the game. From round 1 to 69, the strategy which maximised cumulative rewards was *Aim for 51*. However, the best action in round 70 would be to take all remaining points in the resource. This strategy also makes sense intuitively. In the final round, the game is going to end anyway, so the best way to maximise rewards is to take all remaining points. However, up to this point, the optimal policy would be to harvest as many points as possible while allowing the resource to

replenish close to its maximum level each round. By doing this, the maximum possible number of points would be available for harvest in the final round.

It is noteworthy that, aside from the final round, the optimal policies generated by both the value iteration and backward induction algorithms were identical. It demonstrates that, unless the player knew that the current round of the game was the final round, the optimal strategy would be to harvest such that the resource was depleted to 51 points before it replenished for the next round. Participants in our experiment had no information about the duration of the game and, therefore, the most successful participants should have treated the game as an infinite horizon problem, where each round they took as many points as possible while still allowing the resource to replenish close to its maximum level.

R code for running the finite horizon MDP can be found at:
https://osf.io/8b7av/?view_only=075259b34db4412cbf859562cf384eed

**Supplemental Material C – Evaluating parametric assumptions**

To analyse the effects of health risk factors on resource management outcomes, we wanted to evaluate whether each health risk factor predicted either a.) rounds lasted, or b.) rewards gathered. To do this, we considered running linear regressions. However, prior to this, we needed to evaluate whether our data met the assumptions of linear regression. Linear regressions assume that the residuals of a model are a.) normally distributed and b.) do not exhibit heteroskedasticity. For each potential regression, we ran a Kolmogorov-Smirnov test to see if the residuals of the model were normally distributed. Further, we ran a Breusch-Pagan test to evaluate whether the residuals exhibited heteroskedasticity. Below is the analysis for both Experiment 1 and 2. Several of the regressions did not meet the assumptions, so we decided to analyse the data with non-parametric measures.

***Experiment 1***

*Harmful alcohol use:* A regression with harmful alcohol use as the independent variable and rewards gathered as the dependent variable showed that the residuals were not normally distributed (Kolmogorov-Smirnov: $D(200) = 0.61$, $p = 2.2x10^{-16}$) and demonstrated heteroskedasticity (Breusch-Pagan = 10.89, $p = .0001$). When a regression evaluated whether harmful alcohol use predicted rounds lasted, the residuals were not normally distributed ($D(200) = 0.48$, $p = 2.2x10^{-16}$), though there was little evidence of heteroskedasticity (BP = 2.27, $p = .132$).

*Delay discounting:* When evaluating the effects of delay discounting on rewards gathered, the residuals were not normally distributed ($D(400) = 0.66$, $p = 2.2x10^{-16}$) and showed heteroskedasticity (BP = 13.97, $p = .0002$). The residuals for delay discounting and rounds

lasted exhibited non-normality (D(400) = 0.48, $p = 2.2x10^{-16}$) and heteroskedasticity (BP = 20.37, $p = 6.39x10^{-6}$).

*Psychological distress:* When considering the association between psychological distress and rewards gathered, the residuals were not normally distributed (D(200) = 0.65, $p = 2.2x10^{-16}$), but there was little evidence of heteroskedasticity (BP = 1.80, $p = .18$). The residuals when evaluating rounds lasted exhibited non-normality (D(200) = 0.49, $p = 2.2x10^{-16}$) but no heteroskedasticity (BP = 1.41, $p = .235$).

*Well-being:* The residuals for well-being and rewards gathered were not normally distributed (D(200) = 0.64, $p = 2.2x10^{-16}$), but there was little evidence of heteroskedasticity (BP = 0.26, $p = .612$). When evaluating rounds lasted with well-being, the residuals exhibited non-normality (D(200) = 0.48, $p = 2.2x10^{-16}$), but not heteroskedasticity (BP = 0.59, $p = .442$).

*Financial Literacy:* The residuals for financial literacy and rewards gathered were not normally distributed (D(200) = 0.65, $p = 2.2x10^{-16}$) but did not display heteroskedasticity (BP = 0.15, $p = .70$). When considering rounds lasted and financial literacy, the residuals did not meet the assumption of normality (D(200) = .49, $p = 2.2x10^{-16}$) and exhibited heteroskedasticity (BP = 30.12, $p = 4.06x10^{-8}$).

## ***Experiment 2***

*Harmful alcohol use:*

A regression with harmful alcohol use as the independent variable and rewards gathered as the dependent variable showed that the residuals were not normally distributed (Kolmogorov-Smirnov: D(381) = 0.70, $p = 2.2x10^{-16}$) and demonstrated heteroskedasticity (BP = 6.87, $p = .009$). When a regression evaluated whether harmful alcohol use predicted rounds lasted, the

residuals were also not normally distributed (D(381) = 0.54, $p = 2.2x10^{-16}$) and demonstrated heteroskedasticity (BP = 6.46, $p = .011$).

*Delay discounting:*

A regression with delay discounting as the independent variable and rewards gathered as the dependent variable showed that the residuals were not normally distributed (Kolmogorov-Smirnov: D(381) = 0.69, $p = 2.2x10^{-16}$), though the test for heteroskedasticity was only marginally significant (BP = 3.58, $p = .059$). When a regression evaluated whether delay discounting predicted rounds lasted, the residuals were also not normally distributed (D(381) = 0.56, $p = 2.2x10^{-16}$) and demonstrated heteroskedasticity (BP = 8.21, $p = .004$).

**Supplemental Material D – Scatterplot graphs of the association between sustainable behaviour and individual characteristics**

This section provides additional visualizations of the data. We provide a scatterplot of the association between each individual characteristic (i.e. delay discounting, well-being, etc…) and each measure of sustainable behaviour (i.e. rounds lasted and rewards gathered). On the scatterplot, we also provide the best fit quantile lines. While, in the main text, we measured 19 different quantiles (.05 - .95, in increments of .05), here we only show 10 of the quantile lines (.05 - .95 in increments of .1), since otherwise the graph would be difficult to interpret. In these graphs, the values of each individual characteristic were not normalized to a mean of zero and a standard deviation of one. This was so that values of the measures of the individual characteristics appear in their raw form. However, this means that the beta values seen in the visualizations will not directly match those discussed in the main text.

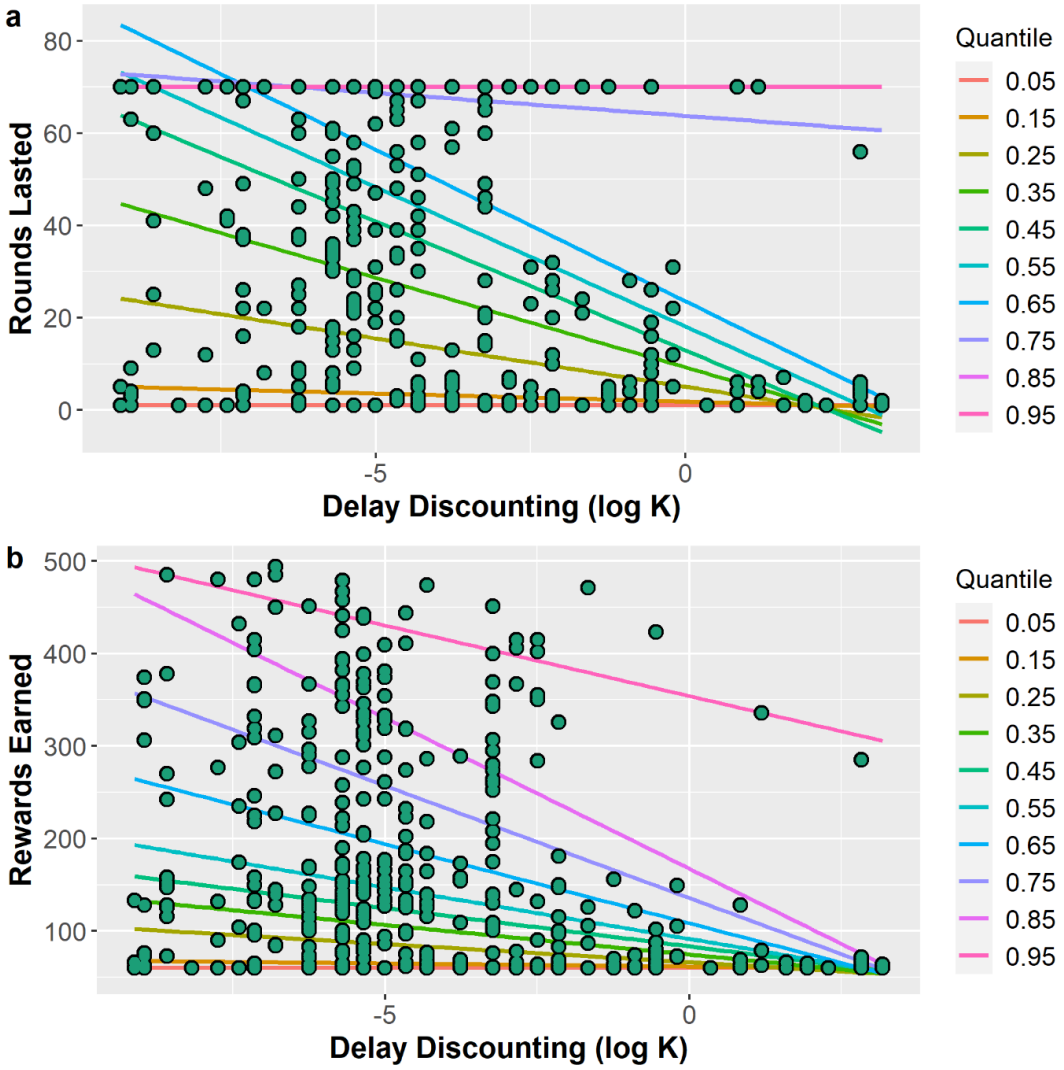



***Figure D.1****. Scatterplot of delay discounting (represented as the log of k) and* ***a.)*** *rounds lasted and* ***b.)*** *rewards earned. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1.*

***Experiment 1***

*Delay discounting:* Figure D.1(a) shows there is little relationship between rounds lasted and delay discounting for low or high quantiles (e.g. the lines representing the 0.05 and 0.95 quantile have little to no slope). However, quantiles near the median exhibit a negative relationship between rounds lasted and delay discounting. Similarly, Figure D.1(b) shows that there is little association between rewards earned and delay discounting among the worst performers (i.e. the 0.05 and 0.15 quantile). However, there is a negative relationship between rewards earned and delay discounting for most of the other quantiles.

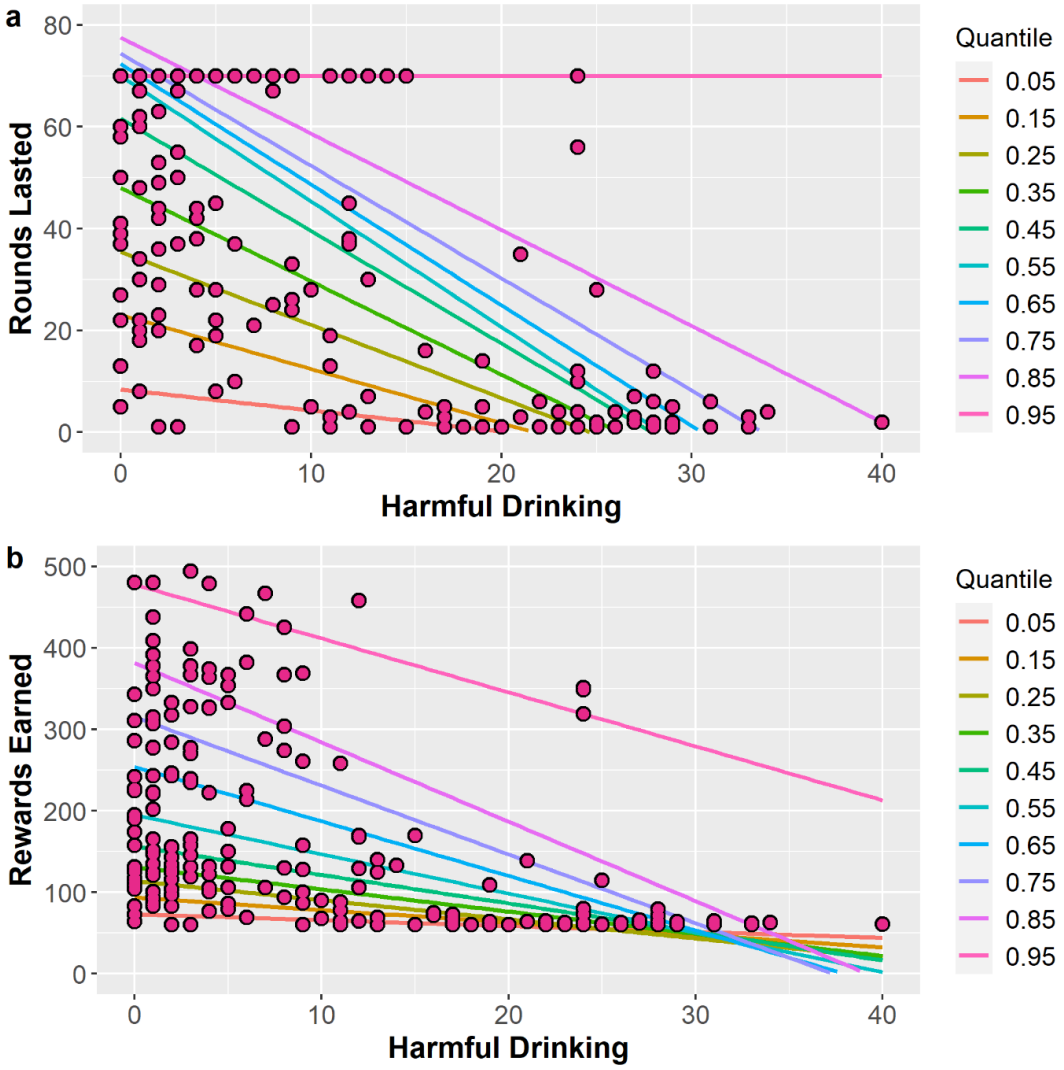



***Figure D.2*** *Scatterplot of harmful alcohol use (as measured using AUDIT) and* ***a.)*** *rounds lasted and* ***b.)*** *rewards earned. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1.*

*Harmful alcohol use:* Figure D.2 illustrates the relationship between harmful alcohol use (as measured by AUDIT) and both rounds lasted (Figure D.2(a)) and rewards gathered (Figure D.2(b)). As shown in Figure 3 in the main text, Figure D.2(a) illustrates that there is a strong negative relationship between harmful use and rounds lasted for every quantile but the highest and lowest. Further, Figure D.2(b) shows that the effect size (i.e. slope of the line) between rewards gathered and harmful alcohol use broadly increases as the quantile increases.

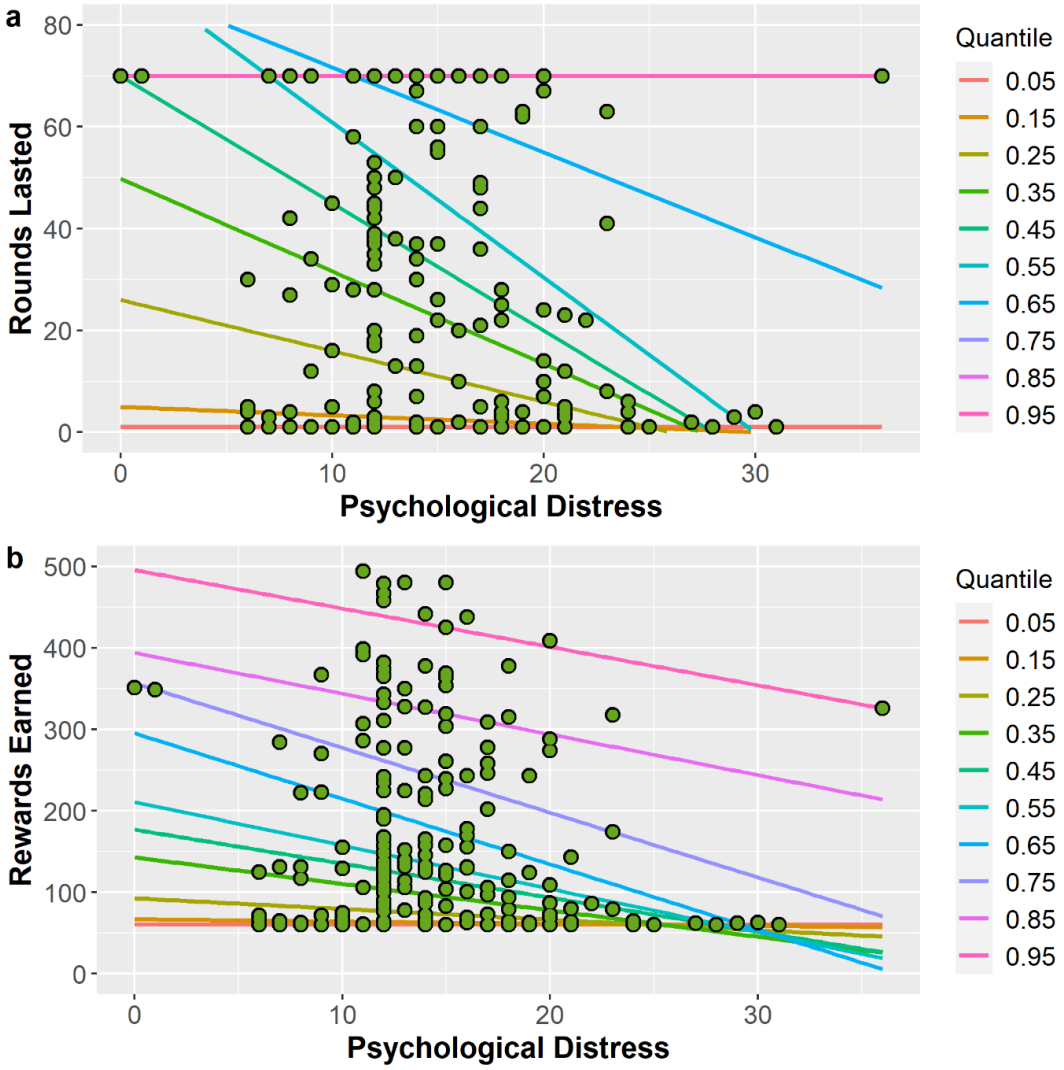



***Figure D.3*** *Scatterplot of psychological distress (as measured using GHQ-12) and a.) rounds lasted and b.) rewards earned. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1.*

*Psychological Distress:* Figure D.3 illustrates the relationship between psychological distress (as measured by GHQ-12) and both rounds lasted (Figure D.3(a)) and rewards gathered (Figure D.3(b)). As shown in Figure 3 in the main text, the strongest negative relationship between psychological distress and both rounds lasted (Figure D.3(a)) and rewards gathered (Figure D.3(b)) occur near the median quantile. However, the effect sizes are weaker compared to delay discounting and harmful alcohol use.

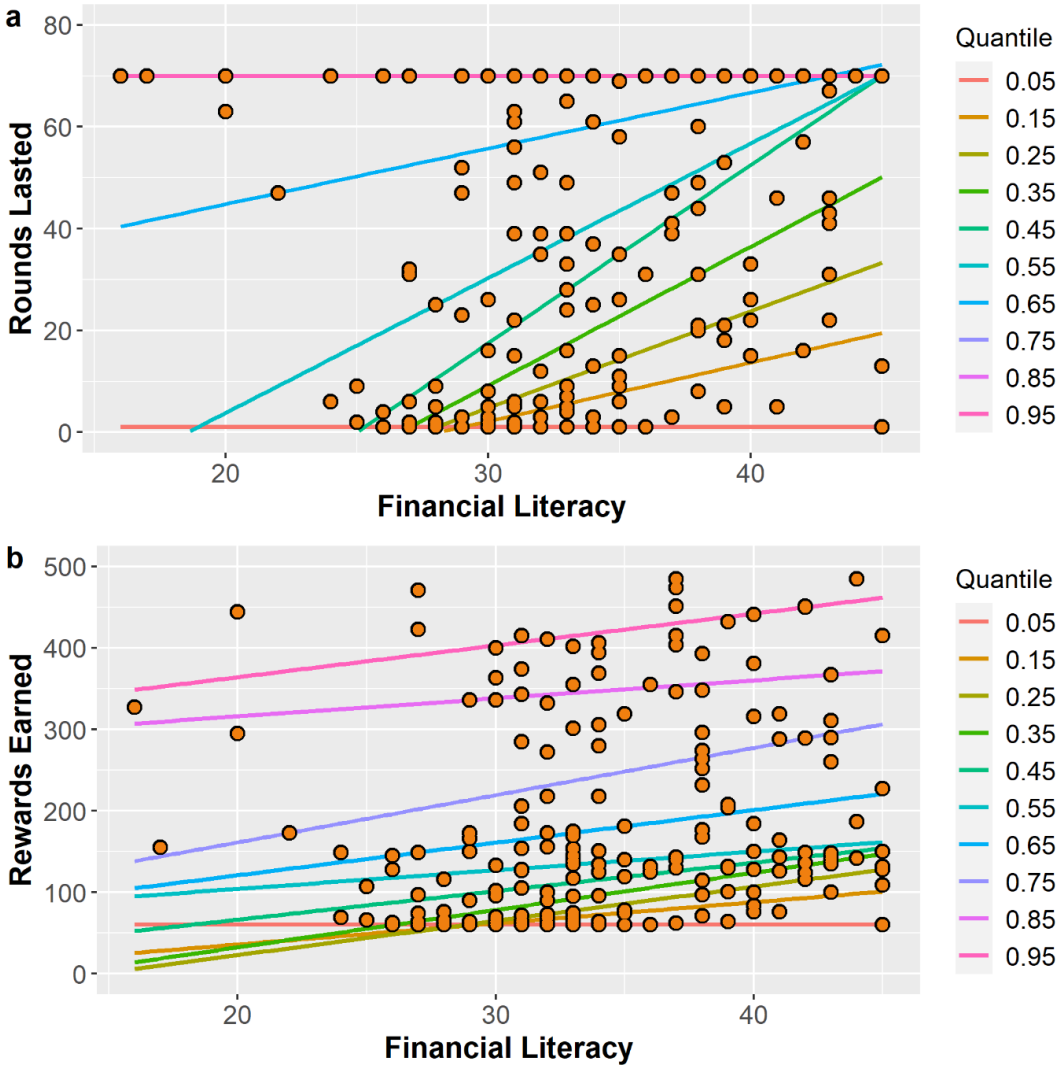



***Figure D.4*** *Scatterplot of financial literacy and* ***a.)*** *rounds lasted and* ***b.)*** *rewards earned. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1.*

*Financial Literacy:* Figure D.4 illustrates the relationship between financial literacy and both rounds lasted (Figure D.4(a)) and rewards gathered (Figure D.4(b)). As shown in Figure D.4(a) (and Figure 3 in the main text), there is a positive relationship between financial literacy and rounds lasted for quantiles in the range 0.15 – 0.65. Figure D.4(b) illustrates that there is a broad positive relationship between financial literacy and rewards gathered for most of the quantiles. However, as discussed in the main text, this effect is less strong than some of the other measures, and only significant for a subset of the quantiles.

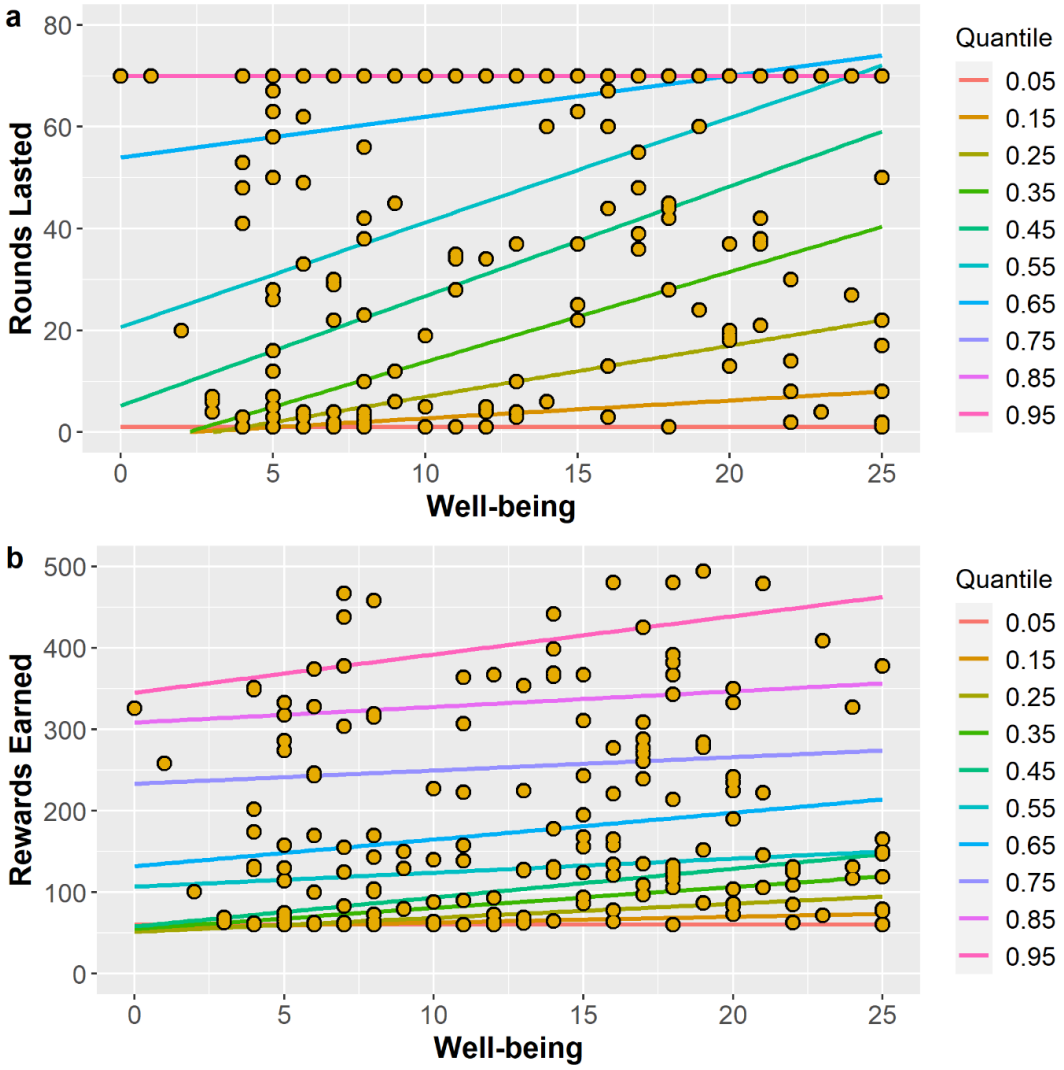



***Figure D.5*** *Scatterplot of well-being (as measured by WHO-5) and* ***a.)*** *rounds lasted and* ***b.)*** *rewards earned. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1.*

*Well-being:* Figure D.5 illustrates the relationship between well-being (as measured by WHO-5) and both rounds lasted (Figure D.5(a)) and rewards gathered (Figure D.5(b)). Well-being is positively related to rounds lasted for several of the quantiles near the median quantile (see Figure D.5(a)). There is a positive relationship in most of the quantiles between well-being and rewards gathered (see Figure D.5(b)). However, only a few of these are significant (please the main text for a discussion).

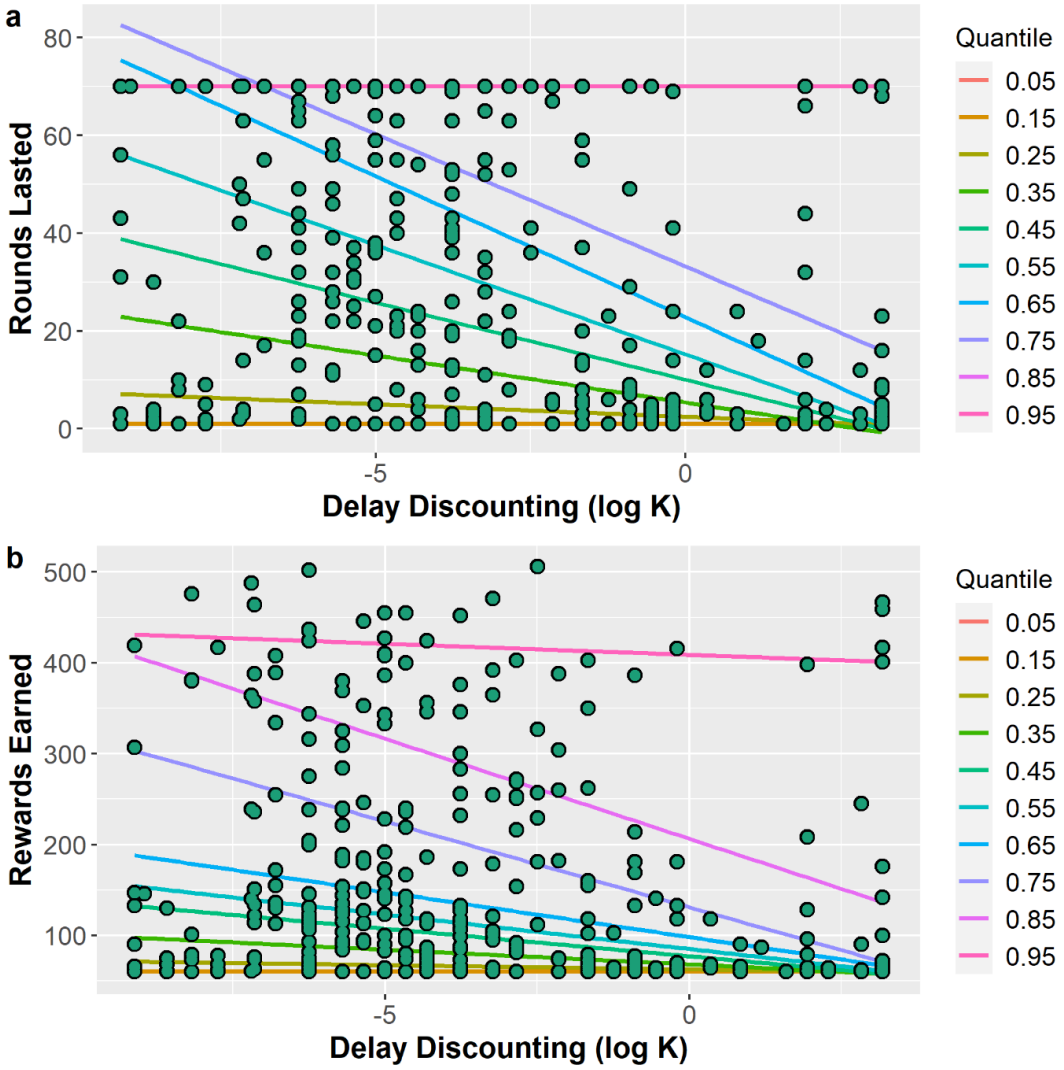



***Figure D.6*** *Scatterplot of delay discounting (as measured by the log of k) and* ***a.)*** *rounds lasted and* ***b.)*** *rewards earned for Experiment 2. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1.*

***Experiment 2***

*Delay discounting:* Figure D.6 illustrates the relationship between delay discounting and both rounds lasted (Figure D.6(a)) and rewards gathered (Figure D.6(b)) for Experiment 2. Broadly, there is a negative relationship between delay discounting and both rounds lasted and rewards gathered. As discussed in the main text (and illustrated in Figure 5), the largest effects of rounds lasted are associated with the quantiles between 0.45 and 0.75. For rewards gathered, Figure D.6(b) shows that the largest negative associations are found at the 0.75 and 0.85 quantile.

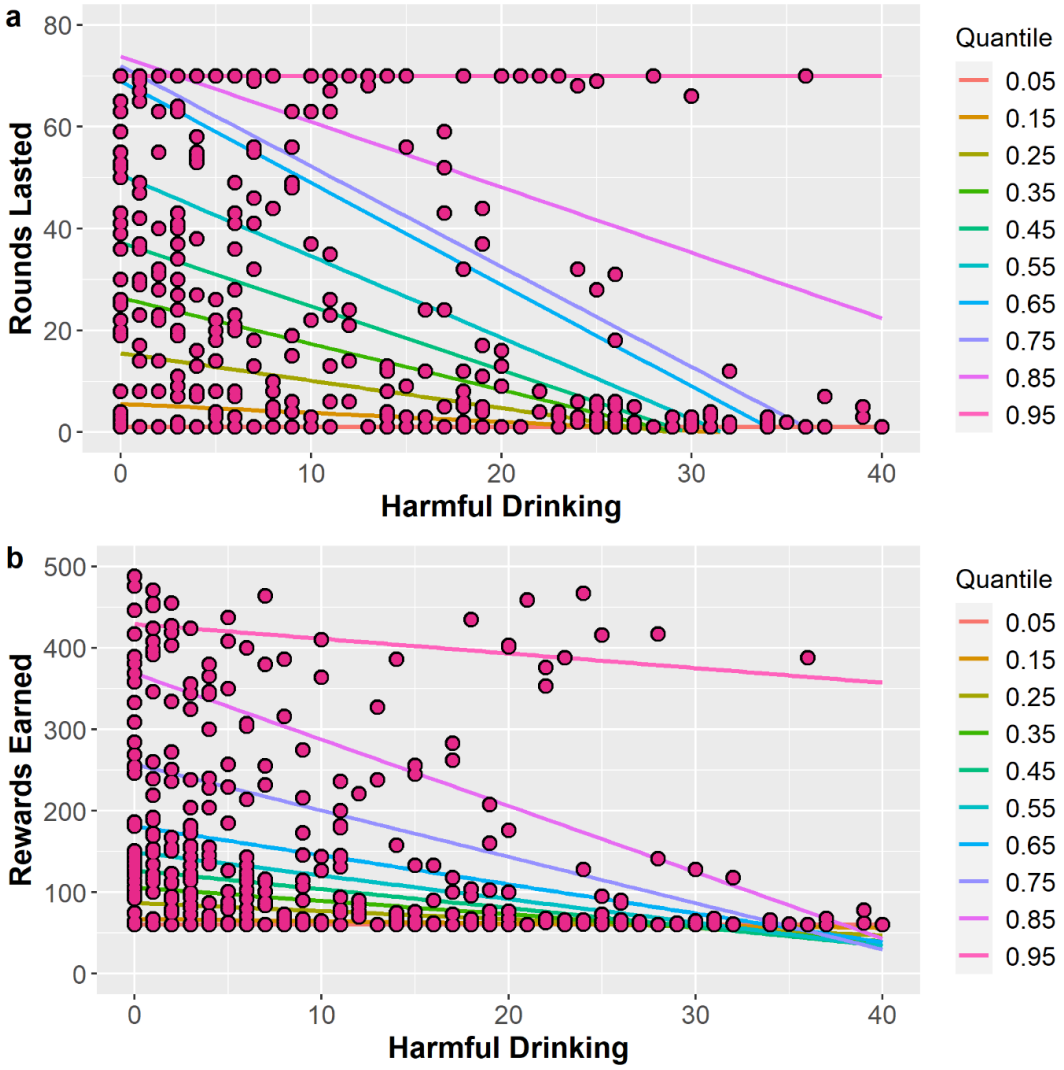



***Figure D.7*** *Scatterplot of harmful drinking (as measured by AUDIT) and* ***a.)*** *rounds lasted and* ***b.)*** *rewards earned for Experiment 2. For each graph the best fit quantile regression lines are included for the quantiles 0.05 - 0.95 in increments of 0.1*

*Harmful alcohol use:* Figure D.7 illustrates the relationship between harmful alcohol use (as measured by AUDIT) and both rounds lasted (Figure D.7(a)) and rewards gathered (Figure D.7(b)) in Experiment 2. Broadly, Figure D.7 illustrates that there is a negative relationship between harmful use and both rounds lasted and rewards gathered. Figure 5 denotes which of the quantiles show a significant association.

## Supplemental Material E – Is the mean replenishment rate correlated with either points gathered, or rounds lasted?

As the replenishment rate was stochastic, it was possible that some participants interacted with a resource that, on average, replenished by a higher or lower proportion compared to other participants. This could, potentially, influence behaviour in the game. To test whether replenishment rates were associated with resource outcomes, we calculated the mean replenishment rate over the first *x* rounds for each participant, and then ran Spearman correlations between these mean replenishment rates and each participant's rounds lasted and rewards gathered. We calculated the mean replenishment rate and ran these correlations for the first 1, 2, 3, 5, 10, 20, 50, and 70 rounds for both experiments; the results of these correlations are summarised in Table E.1 and Table E.2, below. None of these correlations were significant. Therefore, we conclude that the variance in replenishment rates did not lead to any substantial changes in participants' behaviour in the game in either experiment.

***Experiment 1***

***Table E.1****: Results of the Spearman correlations run to determine whether there was an association between the resource's mean replenishment rate and resource outcomes in Experiment 1.* ***x****: the number of rounds used to calculate mean replenishment rate (1 = first round, 2 = first 2 rounds, 70 = all rounds, etc.);* $r_s$*: Spearman's rank correlation coefficient;* ***p:*** *p-value for the Spearman's correlation.*

| *x* | Rounds lasted | | Rewards Gathered | |
|---|---|---|---|---|
| | $r_s$ | *p* | $r_s$ | *p* |
| 1 | -.05 | .336 | .01 | .886 |
| 2 | -.02 | .699 | .05 | .343 |
| 3 | -.04 | .481 | .03 | .533 |
| 5 | -.04 | .384 | .02 | .639 |
| 10 | -.04 | .484 | .02 | .671 |
| 20 | -.02 | .673 | .01 | .799 |
| 50 | -.02 | .746 | .00 | .951 |
| 70 | -.02 | .752 | .02 | .674 |

***Experiment 2***

***Table E.2****: Results of the Spearman correlations run to determine whether there was an association between the resource's mean replenishment rate and resource outcomes in Experiment 2.* ***x:*** *the number of rounds used to calculate mean replenishment rate (1 = first round, 2 = first 2 rounds, 70 = all rounds, etc.);* $\boldsymbol{r_s}$***:*** *Spearman's rank correlation coefficient;* ***p:*** *p-value for the Spearman's correlation.*

| *x* | Rounds lasted | | Rewards Gathered | |
|---|---|---|---|---|
| | $r_s$ | *p* | $r_s$ | *p* |
| 1 | -.06 | .268 | -.03 | .621 |
| 2 | -.04 | .411 | -.01 | .801 |
| 3 | -.05 | .379 | -.02 | .663 |
| 5 | -.03 | .562 | -.02 | .689 |
| 10 | -.03 | .557 | -.03 | .607 |
| 20 | -.04 | .411 | -.01 | .801 |
| 50 | -.04 | .386 | -.02 | .627 |
| 70 | -.04 | .392 | -.03 | .569 |

**Supplemental Material F – The impact of knowing the termination rule on the association between delay discounting and resource management**

Recently, we found that knowing the termination rule for our resource management game improves sustainable behaviour (Rauwolf & Rogers, under review). In the study, half the participants played the game exactly as described in the main text. The other half were given the number of remaining rounds after each harvest – the termination rule. One hundred of those who knew the termination rule also completed the $ED_{50}$ as a measure of delay discounting. This was exploratory analysis, so it was not analysed in the paper. We present the analysis here.

Spearman's correlations showed that delay discounting (as the log of $k$) was negatively associated with both rounds lasted ($r_s(98)= -0.47$, $p = 1.57\text{x}10^{-6}$) and rewards gathered ($r_s(98) = -0.44$, $p=7.47\text{x}10^{-6}$) for the participants who knew the termination rule. Further, the Spearmen's rank correlation coefficient (i.e., the effect size) was larger than that found in either Experiment 1 (rounds lasted: $r_s=-0.31$, rewards gathered: $r_s= -0.27$) and 2 (rounds lasted: $r_s=-0.34$, rewards gathered: $r_s= -0.31$) in the current paper. This suggests that knowing the termination rule did not reduce (and if anything increased) the association between delay discounting and sustainable behaviour.

Figure F.1 illustrates the quantile regression for the participants who knew the termination rule. Figure F.1(a) shows that higher delay discounting was significantly associated with fewer rounds lasted from 0.05-0.50 quantiles. Further, compared to Figure 3(c) and Figure 5(c), the beta values in Figure F.1(a) (which is the effect size) were larger from the 0.05-0.40 quantiles. However, the effect diminished after the 0.50 quantile. Since the participants knew

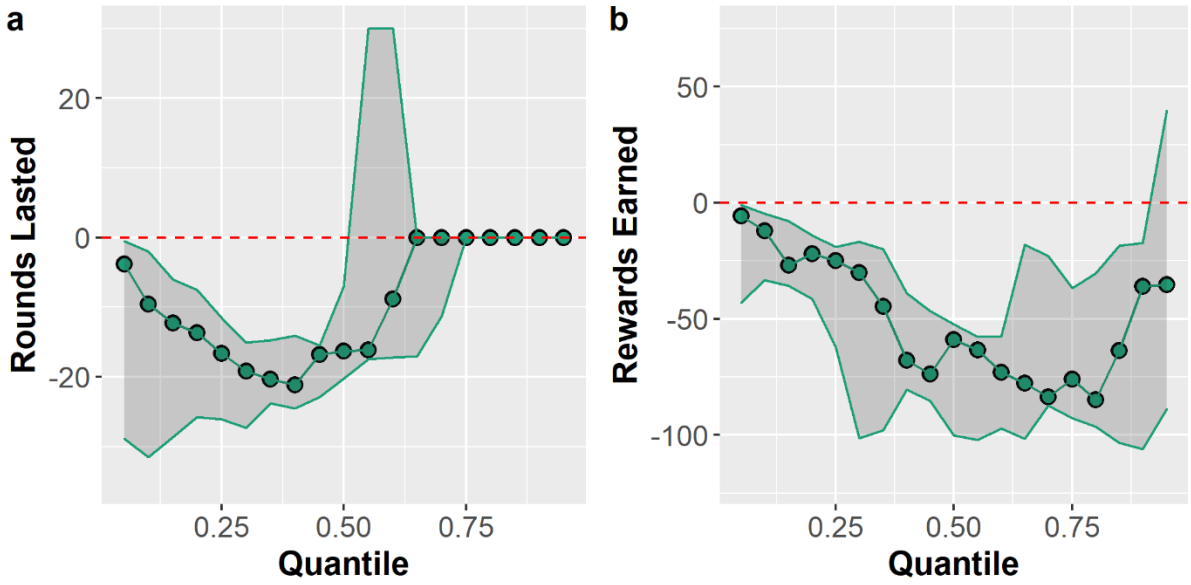



*Figure F.4 Quantile regression of rounds lasted **(a)** and rewards gathered **(b)** against normalized (mean=0; SD=1) delay discounting ($ED_{50}$) from quantiles 0.05-0.95 in increments of 0.05. Shaded areas represent 95% CIs.*

the length of the game, many more sustained the resource for all 70 rounds. Thus, there was no effect of delay discounting in the best performing half of the participants.

Figure F.1(b) illustrates that there is a significant effect of delay discounting on rewards harvested in the quantile range 0.05-0.90. Further, the effect sizes of delay discounting were generally larger in those who know the termination rule, compared to the effect sizes found in the current paper. For example, when estimating median performance (i.e., the 0.5 quantile), one standard deviation increase in delay discounting was associated with a loss of 59 rewards. This was over twice the effect compared to the 27 rewards found in Experient 1 (see Figure 3(d)) and the 23 rewards found in Experiment 2 (see Figure 5(d)).

By comparing Figure F.1 to Figure 3 and 5, it is clear that, in general, knowing the termination rule of the resource management game increased the negative association between delay discounting and sustainable behaviour. Given this, we find it unlikely that the results found in the main text are confounded by the unknown termination rule. We expect that health risk factors are associated with poor sustainable behaviour, regardless of knowledge about the termination rule; however, it would be helpful if future studies extended this exploratory analysis to the other measures used in the current paper.