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Does effort-cost decision-making relate to real-world motivation in people living with HIV?

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ABSTRACT

Introduction: Low motivation is frequent in older people with HIV, yet poorly understood. Effort-cost decision-making (ECDM) tasks inspired by behavioral economics have shown promise as indicators of motivation or apathy. These tasks assess the willingness to exert effort to earn a monetary reward, providing an estimate of the subjective "cost" of effort for each participant. Here we sought evidence for a relationship between ECDM task performance and self-reported motivation in a cross-sectional study involving 80 middle-aged and older people with well-controlled HIV infection, a chronic health condition with a high burden of mental and cognitive health challenges. Methods: Participants attending a regular follow-up visit for a Canadian longitudinal study of brain health in HIV completed a computerized ECDM task and a self-report measure of motivation. Other brain health measures were available, collected for the parent study (cognition, depression, anxiety, and vitality, as well as self-reported time spent on real-world leisure activities). Results: Contrary to our hypothesis, we found no relationship between ECDM performance and self-reported motivation. However, those willing to accept higher effort in the ECDM task also reported more time engaged in real-world activities. This association had a small-to-moderate effect size. Conclusions: The behavioral economics construct of subjective cost of effort, measured with a laboratory ECDM task, does not relate to motivation in people living with chronic HIV. However, the task shows some relationship with real-world goal-directed behavior, suggesting this construct has potential clinical relevance. More work is needed to understand how the subjective cost of effort plays out in clinical symptoms and everyday activities.

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Introduction

Motivation is a key determinant of goal-directed behavior (Mann, 1990; Marin & Wilkosz, 2005). It is a multifaceted construct, implicated in activating, directing and sustaining pursuit of a goal (Strombach et al., 2016). In the clinic, low motivation is a cardinal feature of apathy, together with emotional blunting and unconcern (Marin & Wilkosz, 2005). Apathy is prevalent in chronic conditions that affect the brain, including psychiatric conditions, neurodegenerative disorders, and medical conditions common in older age. Treated human immunodeficiency virus (HIV) infection is one such chronic condition. As people live longer with HIV thanks to antiretroviral treatment, the toll on mental and neurological health is of growing concern (Heaton et al., 2010). Low motivation, most often assessed within the broader construct of apathy, is prevalent in HIV, as is mild cognitive impairment, depression, anxiety, and fatigue (Heaton et al., 2010; Kamat et al., 2016; Kaur et al., 2019). Apathy has been linked to dependence in activities of daily living (Kamat et al., 2012), medication nonadherence (Barclay et al., 2007) and poor mental and physical health-related quality of life in people with HIV (Kamat et al., 2016).

Despite the prevalence and impact of low motivation, whether considered on its own or in the context of the apathy syndrome, little is known about the underlying mechanisms. Relatedly, there is little consensus on how best to identify or treat low motivation. While a descriptive approach to diagnosis relying on clinician interview or self-report has dominated the field so far, there is emerging interest in understanding the contributors to motivated behavior within a neurobiological framework. Behavioral economics and decision neuroscience provide candidate component processes of motivation, along with novel laboratory tasks to assess them.

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Effort-cost decision making (ECDM) tasks focus on the trade-off between effort and reward, a process that would seem important to motivated behavior. Such tasks assess the willingness to produce a given level of physical or cognitive effort in return for a monetary pay-off (Barch et al., 2019; Fellows, 2004; Husain & Roiser, 2018). Participants are offered a series of choices across a range of effort and reward levels, with the overall proportion of offers accepted reflecting individual differences in the subjective cost of effort, at least under the specific experimental conditions. Those who place a lower cost on effort are willing to accept more offers, i.e., are willing to put in more effort for lower pay-offs. This construct has face validity for real-world motivation and the underlying neurobiology has been studied in animal models and healthy humans, with proposed roles for medial prefrontal cortex, striatum, and dopamine modulation (Le Heron et al., 2018; Lopez-Gamundi et al., 2021; Pessiglione et al., 2018; Salamone et al., 2007; Salamone et al., 2016).

ECDM tasks have been tested in healthy people and in some clinical populations. Higher subjective costs of effort, expressed by fewer accepted offers across the set of different effort and reward levels, have been consistently reported in clinical compared to healthy samples (Le Bouc et al., 2016; Culbreth et al., 2018; Horan et al., 2015; Huang et al., 2016; Chong et al., 2015; Chong et al., 2016; Zénon et al., 2016). Whether ECDM performance relates to clinical symptoms is less clear. The most-studied condition is schizophrenia, with a focus on negative symptoms: anhedonia, asociality, blunted affect, alogia and lack of motivation (Blanchard & Cohen, 2006; Millana et al., 2014). A recent review of ECDM in schizophrenia found 10 studies reporting an association between higher negative symptoms and lower proportion of ECDM offers accepted and 5 studies finding no association between these two measures (Culbreth et al., 2018). In a sample of participants with depression, two studies (Hershenberg et al., 2016; Treadway et al., 2012) found that worse depression was linked to a paradoxically increased willingness to accept higher-effort ECDM offers.

One reason for the mixed results could be that the neurobiological mechanisms underlying the variation in subjective cost of effort are different across disorders (Culbreth et al., 2018). Computational modeling can disentangle the two elements that influence ECDM: reward sensitivity and effort sensitivity. Apathy severity was shown to be associated with greater sensitivity to effort in one sample of healthy individuals (Bonnelle, Manohar et al., 2015; Bonnelle, Veromann et al., 2015), and to decreased reward sensitivity in a study of PD patients taking dopaminergic medication (Le Bouc et al., 2016).

Beyond the schizophrenia literature, there are few studies that have investigated the relation between self-reported motivation or apathy and ECDM and none that have tested the specificity of such a relationship: other brain health constructs such as depression, anxiety, poor cognitive performance and fatigue often co-occur with low motivation and might plausibly influence ECDM. While ECDM offers a neurobiologically-informed perspective on clinical symptoms, larger studies in diverse clinical samples are needed to provide clearer evidence for the hypothesized relationship between ECDM and low motivation.

The primary objective of this study is to the estimate the extent to which the subjective cost of effort measured by the proportion of accepted offers in an ECDM task is associated with self-reported motivation in a sample of older people with well-controlled HIV infection. A secondary objective is to contribute evidence for the specificity of this relationship, exploring the extent to which the subjective cost of effort measured by an ECDM task is associated with other brain health constructs including cognition, depression, anxiety, vitality, and an indicator of real-world motivated behavior.

Methods

Participants

A sample of older participants was recruited from the Positive Brain Health Now cohort (BHN), a Canadian longitudinal study of brain health in middle-aged and older people with combination antiretroviral therapy (cART)-treated HIV. The BHN study protocol has been published (Mayo et al., 2016). 117 sequential BHN participants were approached for this sub-study at the time of a routine follow-up visit for the main study at one site in Montreal, of whom 29 declined and 88 accepted. Seven of those who accepted subsequently rescheduled their main study visits and were not available for testing. One participant could not complete testing due to an equipment problem. Thus, data from 80 participants were available for analysis. The 29 who refused participation in this sub-study nonetheless were characterized on available BHN data, to assess selection bias.

Inclusion criteria for the main study were age 35 years or older, stable HIV infection for at least one year, able to communicate in French or English. Exclusion criteria included psychotic disorder, dementia that precluded capacity to consent, life expectancy of <3 years, other neurological disorder likely to affect cognition, current substance use disorder or severe substance use disorder within the past 12 months. There were no additional inclusion or exclusion criteria for this sub-study. The main study and sub-study were both approved by the research ethics board of the McGill University Health Center (Protocol number: 2017–3252). All study participants were compensated for their time and those included in this sub-study received an additional amount that they were told depended on their choices in the task. The total compensation for participating in the sub-study was 15 USDCDN.

Self-report measures

Motivation

Items 1, 2, 4, 6, 7, and 8 of the Starkstein Apathy Scale (AS) were used to assess motivation (Starkstein & Leentjens, 2008; Starkstein et al., 1992). These six questions were chosen based on Rasch analysis (Smith, 2004) of the original 14 AS items, in a separate sample. They include "Does anything interest you?" and "Do you have motivation?." The analytic approach followed the one described in (Hum et al., 2021). For the purposes of presentation, logit scores were transformed to a 0–100 scale with higher scores indicating more motivation. Data from a screening version of 3-items of the AS, scored using the same method, were available for those who refused participation.

Cognitive symptoms

The Communicating Cognitive Concerns Questionnaire (C3Q; Askari et al., 2020) is an 18-item self-report questionnaire targeting specific cognitive concerns relevant to people with HIV. The C3Q assesses memory, attention, executive function and language. The extent to which these items fit a linear hierarchy and form a measure has been tested using Rasch analysis and the validity of summing across the ordinal response scale (frequently, sometimes, and rarely using values of 0, 1 and 2) demonstrated. The total score ranges from 0 to 36, with higher values indicating better cognition (i.e., fewer cognitive symptoms).

Depression and anxiety

The Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) was used to assess anxiety and depression symptoms. This is a 14-item scale with 7 items assessing anxiety and 7 items assessing depression. The linear hierarchy of the items has been tested and the validity of summing the ordinal response options (0 to 3) demonstrated (Pallant & Tennant, 2007). The Cronbach's alpha for HADS anxiety subscale is 0.83 and for HADS depression subscale is 0.82 (Bjelland et al., 2002). To facilitate the comparison between the HADS and the rest of the questionnaires used in this study, the original scale was reverse so that higher scores indicated better mood (i.e., fewer symptoms).

Vitality

The RAND-36 measure of health-related quality of life Energy/Fatigue subscale (Hays & Morales 2001) was used to assess vitality. Example items include "How much of the time in the last 4 weeks did you . . . .have a lot of energy? . . . . feel full of pep?" The Cronbach's alpha of this subscale is 0.86. Final scores range from 0 to 100 scale with 100 being a more favorable health state (more vitality).

Real-world motivated behavior

Participants were asked to indicate the activities they carried out in a typical week, selecting them from a list provided, with the option to specify other activities if needed. The list included reading, checking e-mail, surfing the internet or other computer activities, playing computer games, doing crafts or hobbies, amongst others. If they checked "yes" for any activity, they were prompted to estimate the number of hours they spent on that activity in a week. Given our interest in motivation in the present study, a priori we focused on time spent on cognitively demanding leisure activities as a plausible indicator of real-world self-motivated behavior. We reasoned that physical activity could be constrained by physical limitations in this chronically ill sample with multiple co-morbidities. We did not include time spent on paid work, as many participants were on long-term disability leave or had retired, making paid work less likely to provide a reliable reflection of real-world motivation. Total time spent on all leisure activities was therefore used as the outcome.

Performance measures

Cognitive performance

The Brief Cognitive Ability Measure (B-CAM; Brouillette et al., 2015) includes a series of cognitive tests assessing episodic memory (delayed (10 minute) recall of an 8-word list), attention (Corsi block test), and executive function (Flanker task, Trail-Making Task-B, phonemic verbal fluency). Rasch analysis was then used to develop a global measure of the underlying latent trait (cognitive ability), with a total score ranging from 0–41 with higher scores indicating better cognitive performance.

Effort-cost decision making task

After completion of the questionnaires, participants were seated in front of a computer running Cogent 2000 (www.vislab.ucl.ac.uk) implemented for MATLAB. At the beginning of each session, the participant's maximum voluntary contraction (MVC) was estimated by having them squeeze a hand dynamometer with their dominant hand as hard as they could for a period of 5 seconds, twice. The MVC was the average of these two values. This was labeled "100% force." They were next asked to exert about 50% of that force and hold it for 20 seconds, to familiarize themselves with the subjective experience of the lower force levels that would be required as the physical effort in the ECDM task.

Participants were next asked to cancel out all the letter "e"s on a page of text composed of random letter sequences as quickly as they could for two minutes. The 20% mental effort level corresponded to the number of lines of text completed during these two minutes. Participants were then shown the number of lines corresponding to each of the five mental effort levels that would feature in the ECDM task. The mental work was based in a previous published study that used the same ECDM in healthy adults (Alexander Soutschek et al., 2017).

After these effort calibration procedures, the ECDM paradigm was administered. This was a slightly modified version of the task used in Study 2 in (Bonnelle, Veromann et al., 2015). Participants were asked to make hypothetical choices between different levels of effort for different amounts of monetary reward. Each trial presented an apple tree that showed the reward at stake (number of apples) and the effort level required to gain the reward (trunk height), see, Figure 1. There were six different reward levels (i.e., 0,1, 3, 6, 9, and 12 apples), and six effort levels (i.e., 0%, 20%, 40%, 60%, 80% and 100% MVC). Consequently, there were 36 possible combinations of effort and reward, each appearing once during the six blocks of the task for a total of 216 trials.

Three blocks involved mental effort and three blocks involved physical effort. The type of effort required was indicated at the beginning of each block and at the top of the screen on each trial. Participants decided if they would be willing to make the required effort in order to win the presented reward, responding "yes" or "no" by pressing the right (yes) or left (no) arrow key of a standard keyboard. Responses were self-paced.

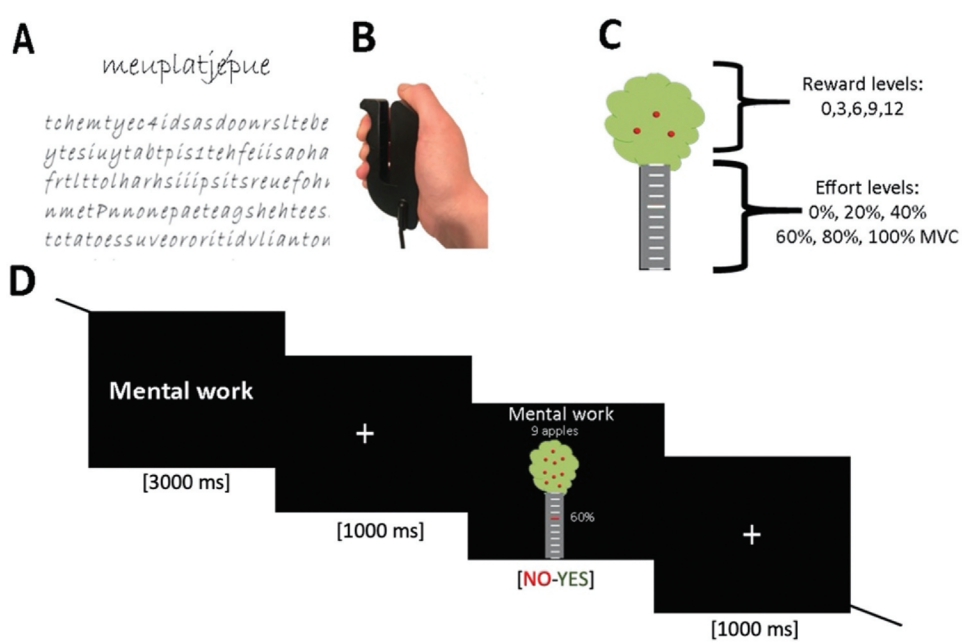

Figure 1. Figure of the ECDM task.
Note: (A). Example of a section of the mental effort worksheet. (B). Handgrip participants used to exert force in the physical force. (C) Summary of the 36 possible effort-reward combinations and an example of the apple tree graphic used to convey these combinations. (D). Example trial of a mental effort block. Participants were presented with the type of block ("mental work" or "physical work") for 3000 ms, followed by a fixation cross for 1000 ms, and the presentation of the choice where participants accepted or rejected the offer. Participants declined offers ("NO") by pressing the left arrow key in a computer keyboard and accepted offers ("YES") by pressing the right arrow key.

Participants were instructed that at the end of the game, one of the trials would be chosen at random, and they would have to play out the selected choice to earn a real monetary reward of up to 15 USD, which would be added to the 40 USD they received for the main study visit. Thus, they were encouraged to make each choice as though it was “for real.” Four practice trials, two involving mental effort and two involving physical effort preceded the main task. After practicing, participants were asked to explain the task in their own words. If needed, the instructions and practice trials were repeated until the task was understood.

The primary outcome of the ECDM task was the proportion of accepted offers across the task (encompassing the set of choices between all six effort and six reward levels). A higher proportion of offers accepted indicates a greater willingness to engage in effort, i.e., a lower subjective effort cost.

Statistical analysis

To characterize the sample, means, standard deviations, and proportions were used. Participants and refusers were compared on demographic and clinical variables using t-tests for continuous variables, Fisher’s exact test for proportions, and logistic regression for brain health measures adjusted for sex and age. Two of these measures (i.e., cognitive symptoms and depression) were used categorically to better fit the models. The primary outcome of the ECDM task was the proportion of accepted offers across all six effort and six reward levels, initially calculated for the mental and physical tasks separately. To estimate the strength of the relationship between proportion of accepted offers in the ECDM task and self-reported brain health measures, spearman rho correlations were calculated.

Following the existing literature, we also applied computational modeling to estimate the separate influence of effort and reward on participants’ choices in the ECDM task (Bonnelle, Manohar et al., 2015) by fitting the choices of each participant to a logistic regression model of choice probability with a softmax function (Equation 1):

$$P(\text{yes}) = \frac{1}{(1 + \exp(b_r x\text{Reward} + b_e x\text{Effort} + b0)}$$

where P(yes) is the probability of accepting an offer, br reflects the sensitivity to reward, be the sensitivity to effort and b0 is the response bias (i.e., selection of a “no” response). Model parameters were optimized by minimizing the negative log likelihood. Spearman rho correlations were conducted to test whether model parameters related to motivation.

Results

Data on 80 participants were included in the analysis. Table 1 shows the demographic and HIV-related clinical characteristics of the participants and refusers. There were no, or negligible, differences between those who participated in the study and those who refused on any of these characteristics.

Table 2 shows the brain health measures for the study sample and refusers. There were no substantive differences between participants and refusers.

EDCM task performance is shown in Figure 2. The mean proportion of accepted offers is displayed as a function of effort and reward. The mean proportion of accepted offers across the entire task was 42.4% (SD = 16.2). There were significant main effects of both effort ($F (5,395) = 164.6$, $p < .001$) and reward ($F (5,395) = 244.4$, $p < .001$) on acceptance, in the expected directions (i.e., trials offering lower effort or higher

Table 1. Demographic and clinical characteristics of the study sample and refusers.

Characteristics	Study sample n = 80			Refusers n = 29		
	Mean or count	*(SD)*	*Median*	*Mean or count*	*(SD)*	*Median*
Age (Years)	56	(8)	55	56	7	57
Women/Men	12/68			4/25		
Education (Years)	14	(2.7)	13	14	2.5	13
Estimated duration of HIV infection (Years)	19.7	(7.3)	21	19.7	9.0	18
Current CD4 (Cells/μL)	647	(258)	621	642	355	569
0–199	1/80 (1%)			3/29 (10%)		
200–500	20/80 (25%)			7/29 (24%)		
> 500	59/80 (74%)			17/29 (66%)		
Nadir CD4 cell count (Cells/μL)	210	(171)	179	231	207	154
Proportion virologically supressed (≤50 copies/mL)	73/80 (91%)			28/29 (97%)		

Table 2. Characteristics of the study sample and refusers on brain health constructs.

Measure	Study sample			Refusers			*OR*	95% *CI*	
	n	*mean*	*(SD)*	*n*	*mean*	*(SD)*		*LL*	*UL*
Self-reported									
SAS-R screening (Motivation) [0–100][a]	80	66.8	(27.5)	29	59	(26.6)	0.99	0.97	1.01
SAS-R (Motivation) [0–100][b]	80	74.4	(21.6)						
C3Q (Cognitive symptoms) [0–36]	78	25.5	(8.3)	28	25.5	(7.8)			
<23 vs 23–30							2.04	0.70	5.92
>30 vs <23							0.73	0.23	2.28
HADS-D (Depression) [0–21][c]	80	16	(3.9)	29	17	(3.3)			
≤14 vs 19–21							0.33	0.09	1.18
15–18 vs 19–21							1.65	0.61	4.43
HADS-A (Anxiety) [0–21][c]	80	14.4	(4.4)	29	14.3	(3.6)	0.99	0.90	1.10
RAND-36 (Vitality) [0–100]	80	55.8	(23.1)	29	56.7	(20.6)	1.00	0.98	1.02
Meaningful activity [hrs/week]	80	38.3	(29.6)	29	28.1	(25.4)	0.99	0.97	1.00
Performance measure									
B-CAM (Cognitive performance) [0–35]	80	21.0	(4.5)	29	20.6	(4.9)	0.98	0.89	1.08

SAS-R = Starkstein Apathy Scale-Rasch; C3Q = Communicating Cognitive Concerns Questionnaire; HADS-D = Hospital Anxiety and Depressive Scale-Depression Score; HADS-A = Hospital Anxiety and Depressive Scale-Anxiety Score; B-CAM = Brief Cognitive Ability Measure.
[a]Motivation was assessed with 3 items from the Starkstein Apathy Scale in the full BHN sample.
[b]The study sample completed 6 items from the Starkstein Apathy Scale.
[c]Transformed from the original score so that higher scores indicate fewer symptoms.

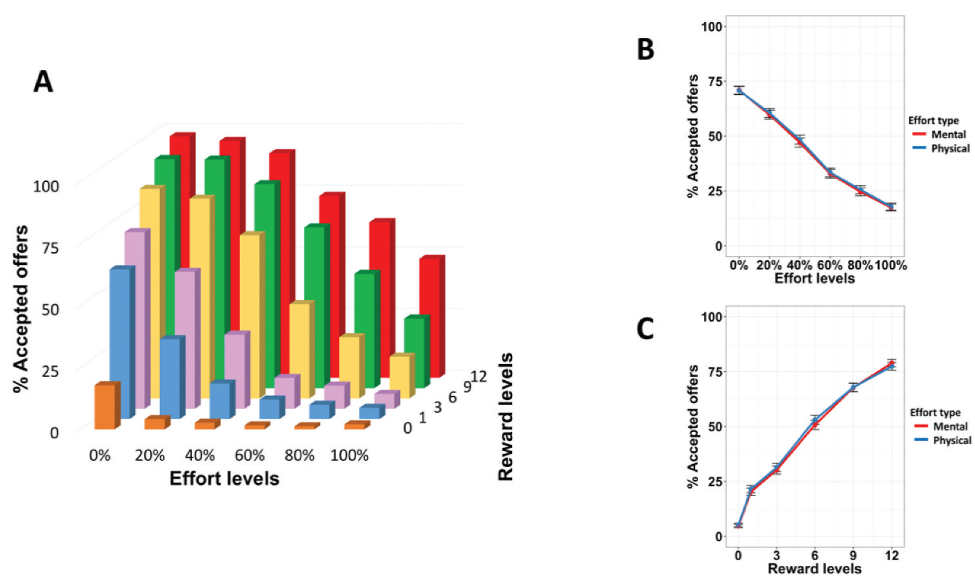

Figure 2. ECDM task performance.
Note: (A). Mean percentage of offers accepted for each of the 36 conditions (6 effort x 6 reward levels). Panels B and C show mean percentage of offers accepted by effort level (B) or reward level (C) with mental and physical effort trials shown separately.

reward were more likely to be accepted). There was also a significant effort by reward interaction (F (25,1975) = 29.38, p < .001). As shown in panels 2B and 2C, there was no difference in the influence of either reward or effort on the mean proportion of accepted offers between the two types of effort. The overall proportion of mental effort trials accepted was 42.1%, SD = 15.9 and of physical effort trials was 42.8%, SD = 17.1; (t (79) = −0.93, p = .353). All subsequent analyses were collapsed across effort type.

We entered each participant's choice data into the model shown in Equation 1 to estimate beta weights for effort sensitivity, reward sensitivity and response bias. Table 3 shows the results of this analysis. Effort and Reward variables were associated with the probability of accept an offer in the ECDM.

As presented in Table 4, the portfolio of brain health measures showed some inter-correlation, with the strongest relationships between depression, anxiety, and fatigue. Motivation, measured with SAS-R, was weakly

Table 3. Results of the choice probability model predicting ECDM choices.

ECDM Outcome	Variables	Parameter Estimate (b)	*M*	*SD*	*SE*	T-statistic	Cohen's d
Probability of accepting an offer in the ECDM task	Effort	Effort sensitivity	−0.85 [a]	0.54	0.06	14.2 [b]	−1.56[c]
	Reward	Reward sensitivity	0.93 [a]	0.64	0.07	13.3 [b]	1.43[c]
		Response bias	−1.22 [a]	2.91	0.32	3.8 [b]	−0.42[c]

[a]For easier visualization, the sign was transformed so that b_e had a negative sign and b_r a positive sign.
[b]T-statistic is equal to β/SE and is equivalent to a t test. A value of ± 1.96 is considered significant.
[c]Cohen's d was calculated as β/SD.

Table 4. Correlation coefficient values among the brain health constructs.[95% confidence intervals]. Values where the confidence intervals exclude zero are shown in bold.

Brain health measures	SAS-R	C3Q	HADS-D	HADS-A	RAND-36	Meaningful activity	B-CAM
Self-reported							
1. SAS-R[a]	–						
2. C3Q	**.35** [0.13, 0.53]	–					
3. HADS-D[b]	**.39** [0.18, 0.57]	**.52** [0.32, 0.67]	–				
4. HADS-A[b]	**.33** [0.12, 0.52]	**.56** [0.37, 0.71]	**.64** [0.47,0.76]	–			
5. RAND-36	**.39** [0.18, 0.57]	**.52** [0.32, 0.67]	**.60** [0.42, 0.73]	**.65** [0.49, 0.77]	–		
6.Meaningful activity	.10 [−0.12, 0.31]	.08 [−0.15, 0.3]	.15 [−0.07, 0.36]	.12 [−0.11, 0.33]	−.02 [−0.24, 0.2]	–	
Performance measure							
7. B-CAM	.06 [−0.16, 0.28]	**.45** [0.24, 0.61]	.22 [0, 0.42]	**.27** [0.05, 0.46]	.11 [−0.11, 0.33]	**.28** [0.06, 0.48]	–

Note: SAS-R = Starkstein Apathy Scale-Rasch; C3Q = Communicating Cognitive Concerns Questionnaire; HADS-D = Hospital Anxiety and Depressive Scale-Depression Score; HADS-A = Hospital Anxiety and Depressive Scale-Anxiety Score; B-CAM = Brief Cognitive Ability Measure. Values in square brackets indicate the 95% confidence interval for each correlation.
[a]Higher scores indicate more motivation.
[b]Scores were reversed from their original score so that higher scores indicate fewer symptoms.

correlated with all other brain health measures. Higher motivation was linked to fewer cognitive and mood symptoms and to more vitality (less fatigue). However, motivation (SAS-R) was not correlated with cognitive test performance (B-CAM) nor, notably, the time spent on real-world activity. Amongst these brain health measures only cognitive test performance showed any relationship with time spent on real-world activity.

Next, we addressed our primary hypothesis, asking whether the primary outcome of the ECDM task was related to motivation. As summarized in Table 5, self-reported motivation (SAS-R) was not related to proportion of accepted offers on the ECDM task. However, meaningful activity was related to proportion of accepted offers on the ECDM task. Scatterplots of these relationships are shown in Figure 3. The secondary ECDM outcome measures, i.e., effort and reward sensitivity parameters were likewise not related to self-reported motivation. There were relationships with anxiety; however, these were not predicted and as such would require confirmation in future work, given the multiple comparisons here.

Discussion

This study investigated whether the subjective cost of effort measured by the proportion of accepted offers in an ECDM task was associated with self-reported motivation in individuals with well-controlled HIV infection. Chronic HIV infection is associated with a high prevalence of mental health symptoms and mild cognitive impairment, likely due to a variety of factors including direct effects of HIV on the brain, cerebrovascular comorbidity, aging and psychosocial factors such as loneliness and stigmatization (Askari et al., 2020). Further, direct viral effects are conventionally thought to target frontostriatal systems (Ances, Ortega, Vaida, Heaps & Paul, 2012; Sanford et al., 2017; Boban et al., 2021; McIntosh et al., 2015; Sanford et al., 2018). Such circuits have been implicated in effort-cost decisions in fundamental work in animal models and human neuroimaging (Le Heron et al., 2018; Lopez-Gamundi et al., 2021; Salamone et al., 2007; Salamone et al., 2016). Thus, a priori, ECDM is a reasonable candidate task for probing behavioral processes likely to be relevant in HIV.

Table 5. Correlation coefficient values for brain health measures and ECDM outcomes [95% confidence intervals]. Values where the confidence intervals exclude zero are shown in bold.

Brain health measures	Proportion of ECDM offers accepted	Effort sensitivity (be)	Reward sensitivity (br)
Self-reported			
1. SAS-R[a]	−.12	−.16	.03
	[−0.35, 0.11]	[−0.38, 0.08]	[−0.22, 0.27]
2. C3Q	−0.18	−.17	.03
	[−0.42, 0.06]	[−0.4, 0.06]	[−0.21, 0.28]
3. HADS-D[b]	−.06	−.20	−.07
	[−0.3, 0.19]	[−0.43, 0.03]	[−0.29, 0.16]
4. HADS-A[b]	−.05	**−.27**	−.11
	[−0.28, 0.19]	[−0.49, −0.05]	[−0.34, 0.11]
5. RAND-36	−.10	−.21	−.10
	[−0.34, 0.14]	[−0.43, 0.02]	[−0.33, 0.13]
6.Meaningful activity	**.23**	.07	.22
	[0, 0.45]	[−0.19, 0.33]	[−0.01, 0.45]
Performance measure			
7. B-CAM	−.13	−.18	.02
	[−0.35, 0.1]	[−0.41, 0.05]	[−0.21, 0.25]

Note: SAS-R = Starkstein Apathy Scale-Rasch; C3Q = Communicating Cognitive Concerns Questionnaire; HADS-D = Hospital Anxiety and Depressive Scale-Depression Score; HADS-A = Hospital Anxiety and Depressive Scale-Anxiety Score; B-CAM = Brief Cognitive Ability Measure.
[a]Higher scores indicate more motivation.
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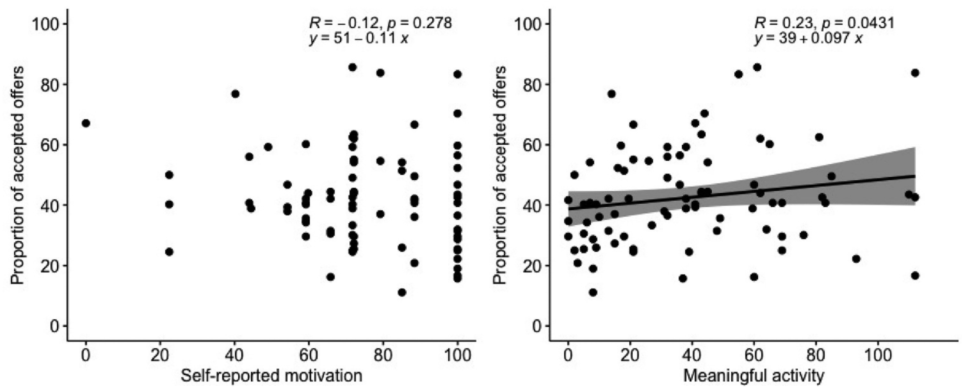

Figure 3. Scatterplots depicting the correlation between proportion of ECDM accepted offers and selected brain health measures. Note: Top right of each panel shows the Spearman rho correlation coefficient and the slope of the linear regression. Shaded areas display the 95% confidence intervals.

The ECDM task we used here seems to have been appropriate to assess the subjective cost of effort construct in this sample. Participants generally made internally consistent choices that varied systematically with reward and effort requirements, and a wide range of individual differences in the subjective cost of effort was observed. However, we did not find support for our primary hypothesis that individual differences in ECDM task performance would relate to self-reported motivation. In a follow-up analysis, we found that ECDM task performance did relate to real-world motivated behaviors, i.e., hours spent on leisure activities in everyday life. The latter analysis was exploratory, so did not correct for multiple comparisons. It needs first to be replicated, and then could be pursued further with a battery of laboratory tasks assessing a wider range of candidate component processes underlying motivated behavior beyond motivation per se, such as executive function, other aspects of decision-making, learning from feedback, and so on (Barch et al., 2019; Fellows, 2004; Husain & Roiser, 2018).

While ECDM tasks have face validity as indicators of motivation, the literature supporting links to clinical symptoms of low motivation or apathy is relatively sparse and conflicting. A few studies investigated the relationship between ECDM and clinical symptoms of motivation, mainly in schizophrenia, with positive and null results reported (Culbreth et al., 2018). Two studies in PD and two in healthy individuals have also addressed this question (Bonnelle, Manohar et al., 2015; Bonnelle, Veromann et al., 2015; Le Bouc et al., 2016; Le Heron et al., 2018), reporting links between apathy scores and ECDM performance. The largely null findings here, in a larger sample and a different chronic health condition, suggest that this relationship is not robust. Of note, the proportion of accepted offers in our task appears to be similar to that observed in other studies using similar tasks, arguing that the failure to replicate is not due to major differences in the subjective cost of effort across samples, nor to differences in the methodological details of the ECDM tasks used across this literature.

For various reasons, correlations between self-report and behavioral measures are inherently weak (Goodwin et al., 2006). The correlation is likely to be even weaker if one measure has poor reliability (Dang, King, & Inzlicht, 2020). The small literature using ECDM tasks in healthy individuals and schizophrenia has raised questions about test-retest reliability and external validity (Horan et al., 2015; Reddy et al., 2015). However, our findings provide some preliminary evidence for external validity for the ECDM task, given the observed association between task performance and an indicator of real-world motivated behavior. Nonetheless, the lack of a consistent relationship with more specific behavioral constructs of theoretical relevance, notably motivation, raises questions that require further study.

An additional consideration is the validity of the self-reported motivation assessment we used. The items were selected from the widely-used Starkstein Apathy Scale (Starkstein & Leentjens, 2008; Starkstein et al., 1992), based on Rasch analysis, a process that yields a semi-quantitative measure of a single construct (i.e., motivation). This modern psychometric approach should yield a more meaningful score than the full instrument, given that we found several mis-fit and redundant items in the conventional SAS (see, also, Hum et al., 2021).The observed correlations between the SAS-R score and other self-reported brain health constructs such as vitality, cognition and depression provide some evidence for the validity of this approach to assessing self-reported motivation. There is a clear need for more psychometrically and conceptually robust self-report measures of motivation to advance this line of research in HIV and in other conditions affecting brain health.

Participants also reported the time spent doing leisure activities. We reasoned that motivation was amongst the capacities required for engagement in "optional" self-directed behaviors of this sort (Marin & Wilkosz, 2005b). While greater engagement in activities likely implies more motivation, less engagement could be due to difficulties in other capacities, perhaps explaining the lack of correlation between this variable and self-reported motivation. The finding that time spent on meaningful activities was the only measure related to cognitive performance assessed with a laboratory (computerized) measure of cognitive ability that assesses memory, attention and executive function, and the only one related to proportion of accepted offers in the laboratory ECDM task, suggests that working back from reported real-world engagement to better define the specific behavioral and neurobiological processes that limit real-world activities in people living with chronic illnesses that affect the brain may be a fruitful strategy.

People with low motivation may be less willing to participate in research. A strength of the present study is that the participation rate was high, and we assessed potential selection bias by comparing those who agreed to participate in this study with those who refused. There were no substantial demographic or clinical differences between these groups. This study drew on a cohort (the BHN study) that was recruited from consecutive patients at a specialized HIV clinic at a tertiary care hospital. We also characterized selection bias in the main BHN sample, finding that those who refused were generally younger and less concerned about brain health symptoms (Mayo et al., 2018). Thus the sampling frame for the current study is likely to overrepresent those with lower levels of motivation and worse brain health, a group for whom motivation assessment may be most clinically relevant. We note, however, that this sampling approach meant that relatively few women were included here, reflecting the relatively small proportion of people living with HIV in Canada who are women. More work is needed to confidently generalize the findings to women with HIV.

In summary, we find mixed support for the claim that individual differences in subjective cost of effort as assessed by a laboratory ECDM task grounded in neuroeconomics relates to clinical symptoms of low motivation or related brain health constructs in older people living with chronic HIV infection. This is a challenge to the assumption that fundamental research on ECDM can be directly applied to clinical conditions marked by low motivation. However, the observed link between ECDM choices and real-world activity, while a small effect with a risk of being a false positive, merits further study. This observation also suggested that new patient-centered outcome measures of low motivation might be usefully validated against engagement in real-world activities, whether self-reported or assessed by activity monitors. Filling these measurement gaps is a precondition for developing a robust understanding of the neurobiological mechanisms underlying motivational deficits in neurological and psychiatric disorders.

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Availability of data and material

Data is available only to editors and reviewers upon request.

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