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The moderating effect of the psychosocial working conditions (effort/reward/overcommitment) on the association between noise annoyance and cognitive performance among adolescents

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Abstract

Objectives The primary objective of the current study was to evaluate the correlation between noise-induced annoyance and the cognitive performance within the Lebanese adolescent population and the moderating effect of psychosocial work aspects-namely effort, reward, and overcommitment- in this association.

Methods An anonymous online survey was conducted in Lebanon between April and May 2023, using a snowball sampling technique and distributed across various social media platforms, to gather data from Lebanese adolescents. The sample was composed of 1269 adolescents. Participants voluntarily completed a self-administered Arabic questionnaire that consisted of a sociodemographic section and implemented three scales: Noise Annoyance scale, Effort-Reward in school scale, as well as LEAF scale.

Results The moderation analysis findings revealed that at low levels of effort, higher noise annoyance was significantly associated with worse memory function (Beta = 0.94; p = .002) and mathematics skills (Beta = 0.40; p = .002), whereas at low (Beta = 0.49; p < .001) and moderate (Beta = 0.29; p = .001) levels of effort, it was significantly associated with worse sustained sequential processing. At low and moderate levels of reward, higher noise annoyance was significantly associated with worse attention (Beta = 0.48; p < .001 and Beta = 0.20; p < .031 respectively), sustained sequential processing (Beta = 0.43; p < .001 and Beta = 0.22; p = .013 respectively) and working memory (Beta = 0.47; p < .001 and Beta = 0.28; p = .002 respectively). At low levels of reward, higher annoyance was significantly associated with worse memory function (Beta = 0.82; p = .007), processing speed (Beta = 0.38; p = .001) and mathematic skills (Beta = 0.28; p = .026). Finally, at low and moderate levels of overcommitment, higher noise annoyance was significantly associated with worse factual memory (Beta = 0.49; p < .001 and Beta = 0.25; p = .005 respectively), worse

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attention (Beta = 0.45; p <.001 and Beta = 0.26; p =.005 respectively) and worse processing speed (Beta = 0.43; p <.001 and Beta = 0.23; p =.012 respectively).

Conclusion This study could encourage the integration of targeted interventions and strategic measures that address both noise annoyance and psychosocial working conditions, defined as the academic work students perform both at school and at home, to proactively prevent the emergence of cognitive impairment among the adolescent population.

Keywords Noise annoyance, Adolescence, Effort-reward imbalance, Cognitive performance, Lebanon

Background

Environmental noise has garnered considerable recognition as an omnipresent unwanted sound, an archetypical environmental stressor that threatens individuals as well as public health [1, 2]. As a result, noise was included as a primary concern on the World's Health Organization's (WHO) register of environmental stressors [3]. Annoyance was found to be the most frequent subjective reaction within a population subjected to ambient noise [4, 5]. It is generally believed that noise-induced annoyance arises from its interference with daily activities, communication, cognitive processes, and sleep patterns, potentially coupled with negative responses including mild anger, fear, and stress-associated reactions [4, 5]. In accordance to Lazarus' transtheoretical stress model [6], stress emerges as a result of a person's incapacity to effectively address environmental challenges, which exceed the scope of his accessible resources. Undoubtedly, observational and experimental studies have demonstrated that noise can evoke extra-auditory effects [7], including stress reactions that activate the autonomic and endocrine system [8, 9]. Noise annoyance is widely perceived to be a stress reaction to ambient noise [5, 6, 10], an indicator of the distress and unease triggered by noise exposure, exerting a significant impact on mental health [11–13]. A comprehensive analysis, presented through a systematic review of the WHO's recommendations on environmental noise, has effectively evaluated the impact of noise on mental well-being [9], supported by precise assessments elucidating the adverse effects of noise on irritation [14], cognitive abilities [15], and sleep patterns [16]. According to WHO, the loss of 1.6 million healthy life years (DALYs, disability-adjusted life-years), each year, in western European countries (comprising approximately 340 million inhabitants) is attributed to environmental noise exposure. The primary contributors to this significant burden are noise-induced sleep disturbance and annoyance [17, 18]. In fact, it is calculated that DALYs (disability adjusted life years) due to noise exposure in Western European nations comprise 45,000 years attributed to cognitive function impairment in children, 903,000 years due to sleep problems, and 587,000 solely attributable to annoyance [18, 19].

Particularly, WHO revealed that nearly 45,000 disability-adjusted life-years (DALY) are lost annually among children aged from 7 to 19 years within western European countries due to noise exposure [15, 18]. Research findings suggests that noise may exert a more significant effect during the execution of tasks involving increased cognitive demands, implying that adolescents undertaking more challenging academic work may be more particularly susceptible to noise disturbances compared to children [20, 21]. Furthermore, gender does not appear to exert any influence on noise-induced annoyance [20–22]. In fact, adolescents, within the age range of 13–15 [23] and 11–18 [20], are often posited to constitute a vulnerable age group [24] that naturally exhibit a heightened susceptibility to the adverse extra-auditory health implications of noise, which correlates with increased rates of annoyance. A comprehensive cumulative analysis of more than twenty studies have consistently demonstrated the deleterious implications of environmental noise-induced annoyance on adolescents' educational attainment and cognitive capabilities [25, 26]. Studies have demonstrated that even within healthy population, environmental noise functions as a distractor, increasing cognitive burden and compromising operational efficiency and task completion by diverting and redirecting cognitive resources away from the task to accomplish [27]. It is true that executive functioning undergoes significant development throughout adolescence [28]. However, studies have demonstrated that adolescent's cognitive abilities to comprehend and foresee stressors are comparatively limited and underdeveloped, and their coping mechanisms have not yet fully developed [29, 30]. Therefore, considering their concurrent physical and cognitive growth, there exists a conceivable risk that noise exposure may engender enduring and persistent deleterious consequences [31].

The relationship between subjective occupational stress and mental well-being was explored using the effort-reward imbalance (ERI) questionnaire, a validated psychosocial measure, founded on Siegrist et al.'s model [22]. This tool assesses the balance between work-related effort and subsequent rewards obtained, and applies beyond workplace settings, extending to social relationships within the household, including marital and parental relationships, as well as other civic responsibilities, thereby reinforcing the model's broad applicability [32, 33]. Moreover, overcommitment - a coping pattern defined by an incapacity to disengage from work in favor of recovery- was assessed by retrieving individual responses to increased effort and minimal reward obtained in the workplace [34, 35]. In line with these findings, further epidemiological and experimental psychobiological investigations also suggest that effort-reward imbalance contributes to increase the stimulation of the autonomic system, causing emotional and psycho-physiological stress reactions, and inducing a range of detrimental health outcomes [36–38]. Studies have shown that individuals perceiving low social support within the work environment as well as lacking a sense of motivation through work-related rewards were significantly associated with having hyperacusis [39], which is defined as debilitating loudness intolerance disorder, associated with an abnormal annoyance to noise [40]. Being overcommitted at work increased the risk of hyperacusis that can evoke noise annoyance [39, 40]. The lack of reciprocity between efforts expended, rewards obtained and overcommitment was inversely associated with overall work-related fulfillment and satisfaction [41–43]. Among the primary mechanisms contributing to these outcomes is learned helplessness, characterized by an individual's sense of powerlessness due to perceived lack of control over noxious environmental stimuli [64–66] which can increase vulnerability to stress and impair task performance.

Furthermore, studies have documented the pervasive influence of noise pollution, noting elevated levels of annoyance, and reduced quality of life. However, the impact of noise-induced annoyance on cognitive performance remain largely unexplored [44, 45].

Considering the increased vulnerability of adolescence to the effects of noise pollution, a study conducted within Lebanon, a country marked by noise exposure levels exceeding the international guidelines of the World Health Organization (WHO) [46, 47], would yield valuable insights into the complex interplay of these variables and thus hold significant research merit. The primary objective of the current study was to evaluate the association between noise-induced annoyance and the cognitive performance within the Lebanese adolescent population. Nonetheless, the existing corpus of research remains limited in its comprehensive examination regarding the relationship between noise annoyance and the cognitive skills in relation to psychosocial work aspects, particularly within the adolescent demographic. In this study, we aimed to adapt the ERI model within an educational environment, where "working conditions" denote the academic work students engage in both at school and at home, adapting its principles to a setting which varies from the model's customary workplace applications. Accordingly, our research aimed to assess the hypothesis that the psychosocial work aspects-namely effort, reward, and overcommitment- serve as moderators, exerting an influence on the relationship between noise-induced annoyance and the cognitive performance within the Lebanese adolescent population. In this context, we hypothesize that psychosocial work factors (effort/reward/overcommitment) may alter the degree to which noise annoyance affects cognitive performance, with varying levels of effort, reward and overcommitment potentially intensifying or reducing the impact of noise annoyance on specific cognitive processes, such as attention, memory and executive functioning (Fig. 1).

Methods

Study design and procedure

An online anonymous survey served as the basis for this descriptive cross-sectional observational study. The voluntary survey was conducted on the Lebanese people throughout Lebanon between April and May 2023. A snowball sampling strategy was implemented for the survey, by using the online Google Forms platform. Distribution of the poll extended across various social media platforms such as WhatsApp, LinkedIn, and Facebook. Adolescents who chose not to participate in the questionnaire were omitted from the study. The "data duplicate" feature in excel was employed to verify that no participate submitted duplicate responses. Participants were instructed in the introductory section to obtain parental consent prior to engaging in the survey. Upon granting digital informed consent, participants were directed to complete the instruments described above, which were arranged in a pre-randomized order to mitigate any potential order effects. The survey guaranteed anonymity, and participants voluntarily participated without receiving any form of compensation.

Minimal sample size

A minimum sample size of 473 adolescents was considered essential to ensure adequate statistical analysis, as determined by the G-power software (Multiple regression: R^2 deviation from zero), based on $R^2 = 0.05$, alpha error = 0.05, power of 95% and 10 predictors to be included in the final model.

Questionnaire

The self-administered questionnaire, written in Arabic, Lebanon's native language, was provided anonymously and required approximately 20 min for completion. Participants were specifically advised to complete the questionnaire without seeking assistance in order to ensure the integrity of their responses. The questionnaire's first section assessed participants' sociodemographic

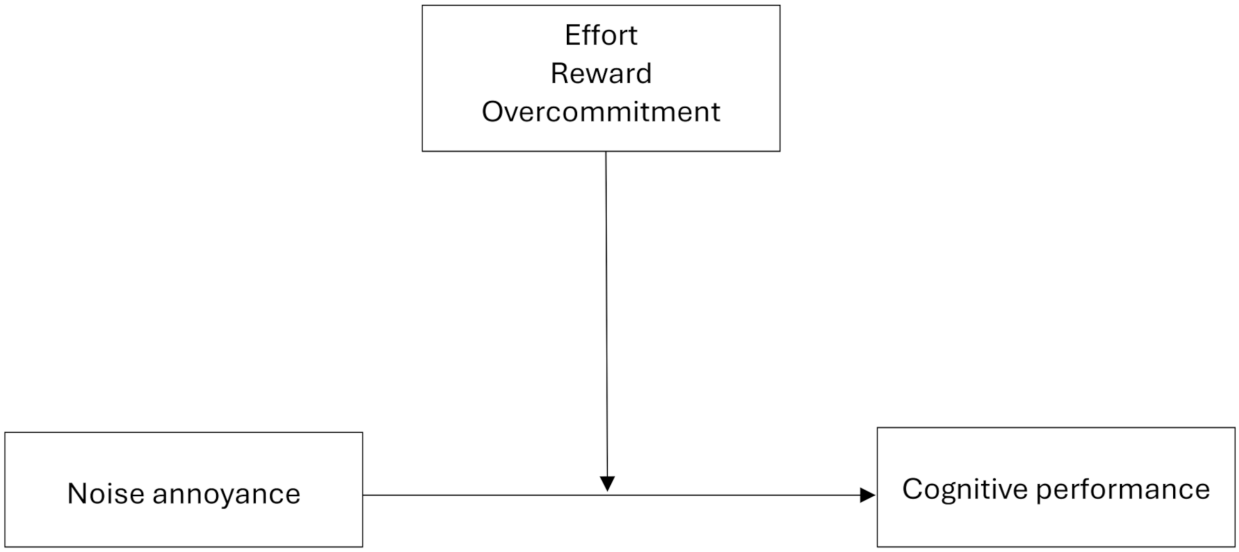

Fig. 1 Moderating effect of effort/reward/overcommitment between noise annoyance and cognitive performance

information. Furthermore, the household crowding index was calculated by dividing the total number of individuals residing in the household by the total number of rooms, with exclusion of those designated for bathroom and kitchen functions [48]. The subsequent section of the questionnaire incorporated the following scales:

Noise annoyance scale

Noise annoyance was assessed using a single question "Does noise in your home or school environment annoy you?" and rated from 1 (= never) to 5 (= always). The question was inspired from the study of Stansfeld et al. [49] where participants self-reported noise annoyance by answering the following question: "Does traffic noise at home annoy you?" We reformulated the question by replacing "at home" by "home or school environment" to fit the study objectives.

Effort reward in school scale

The study consisted of a 19-item questionnaire and involved the assessment of extrinsic components such as the effort component, comprising 5 elements related to homework and expectations, and the reward component, which consisted of 11 items including academic success, esteem, and educational prospects, as well as the intrinsic factor of overcommitment, which included 3 elements [50]. Using a five-point Likert scale, survey respondents rated their level of agreement with the questionnaire statements, with options spanning across "strongly disagree" to "strongly agree". Higher scores on this scale reflect increased levels of effort, reward and overcommitment. The Cronbach's alpha values were assessed, indicating the ensuing values: effort ($\alpha = 0.82$), reward ($\alpha = 0.80$) and overcommitment ($\alpha = 0.80$).

Language-revised learning, executive, and attention functioning (LEAF) scale

The LEAF, consisting of 55 items, serves as a questionnaire administered to parents, teachers, or self-report evaluations, aimed at assessing executive functioning, associated neurocognitive functions, as well as academic proficiency across both children and adults. Responses to all items within the survey were rated using a four-point Likert scale (0 = never to 4 = very often) [51]. Authorization to use this scale was granted by Pr. William Kronenberger. This scale yields 12 scores as follows: comprehension and conceptual learning ($\alpha = 0.85$), factual memory ($\alpha = 0.84$), attention ($\alpha = 0.87$), processing speed ($\alpha = 0.84$), visual-spatial organization ($\alpha = 0.78$), sustained sequential processing ($\alpha = 0.82$), working memory ($\alpha = 0.86$), novel problem solving ($\alpha = 0.85$), mathematics skills ($\alpha = 0.86$), basic reading skills ($\alpha = 0.90$) and written expression skills ($\alpha = 0.83$). Higher scores indicate worse aspect in each dimension. The scale was administered in Arabic; the forward translation was done by one translator. An expert committee formed by healthcare professionals and a language professional verified the Arabic translated version. A backward translation was then performed by a second translator, unaware of the initial English version. The back-translated English questionnaire was subsequently compared to the original English one, by the expert committee. Discrepancies related to inadequate expressions and concepts, confusing in meaning and slightly off in meaning during the reconciliation of

Table 1 Sociodemographic and other characteristics of the participants

	Mean ± SD in this study
Noise annoyance	2.01 ± 1.09
Memory function	20.53 ± 9.01
Comprehension and conceptual learning	4.29 ± 3.20
Factual memory	4.63 ± 3.38
Attention	5.12 ± 3.60
Processing speed	5.03 ± 3.49
Visual-spatial organization	4.54 ± 3.27
Sustained sequential processing	4.69 ± 3.36
Working memory	5.01 ± 3.53
Novel problem solving	4.02 ± 3.30
Mathematics skills	5.07 ± 3.70
Basic reading skills	4.04 ± 3.58
Written expression skills	4.29 ± 3.31
Effort	16.63 ± 4.15
Reward	36.00 ± 5.90
Overcommitment	9.09 ± 2.93

the back translated questionnaire with the original source were resolved by consensus.

Statistical analysis

The SPSS software v.26 was employed for statistical analysis. The normal distribution assumption was satisfied for all LEAF subscale scores, given that skewness and kurtosis values varied within ±1. A multivariable analysis MANCOVA was conducted taking noise annoyance as the independent variable and each LEAF subscale score as the dependent variable. The moderation analyses were completed using PROCESS MACRO (an SPSS add-on) v3.4 model 1 [52], using effort/reward/overcommitment as moderators in the relationship between noise annoyance and each LEAF subscale score. Interaction terms were probed by examining the association of one predictor with psychotic-like experiences at the mean, 1 SD below the mean and 1 SD above the mean of the moderator. Results were adjusted over age, gender and household crowding index (taken as covariates in each model). $P < .05$ was regarded as statistically significant.

Results

Sociodemographic and other characteristics of the participants

The sample consisted of 1269 adolescents, exhibiting a mean age of 15.68 ± 1.75 years (min = 12; max = 18), and 771 (60.8%) females. The mean household crowding index was 1.28 ± 0.62 persons/room. Other descriptive results can be found in Table 1.

Bivariate analysis

Higher mean mathematics skills, effort and overcommitment scores were significantly found in females compared to males (Table 2). It is noteworthy that none of the scores was significantly associated with age and household crowding index (Table 3).

Multivariable analysis

The MANCOVA results revealed that higher noise annoyance was significantly associated with worse memory function, comprehension and conceptual learning, factual memory, attention, processing speed, visual spatial organization, sustained sequential processing, working memory, novel problem solving, mathematics skills, basic reading skills and written expression skills (higher scores for all) (Table 4).

Table 2 Comparison of LEAF scores between genders

	Males Mean ± SD	Females Mean ± SD	*p*	Effect size
Memory function	20.22 ± 9.20	20.73 ± 8.89	0.333	0.056
Comprehension and conceptual learning	4.20 ± 3.08	4.35 ± 3.28	0.407	0.048
Factual memory	4.40 ± 3.29	4.77 ± 3.43	0.053	0.111
Attention	4.99 ± 3.54	5.20 ± 3.64	0.316	0.058
Processing speed	4.87 ± 3.44	5.14 ± 3.52	0.188	0.076
Visual spatial organization	4.66 ± 3.37	4.46 ± 3.21	0.287	0.061
Sustained sequential processing	4.72 ± 3.46	4.67 ± 3.29	0.805	0.014
Working memory	4.81 ± 3.50	5.14 ± 3.54	0.095	0.096
Novel problem solving	4.06 ± 3.34	3.99 ± 3.28	0.687	0.023
Mathematics skills	4.75 ± 3.64	5.28 ± 3.72	**0.011**	0.146
Basic reading skills	4.22 ± 3.76	3.93 ± 3.46	0.156	0.082
Written expression skills	4.43 ± 3.37	4.20 ± 3.28	0.225	0.070
Effort	16.23 ± 4.21	16.89 ± 4.09	**0.006**	0.157
Reward	36.14 ± 5.94	35.90 ± 5.88	0.487	0.040
Overcommitment	8.82 ± 2.93	9.26 ± 2.91	**0.009**	0.150

Numbers in bold indicate significant *p* values. LEAF = Language-Revised Learning, Executive, and Attention Functioning scale

Table 3 Pearson correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Memory function	1															
2. Comprehension and conceptual learning	0.36***	1														
3. Factual memory	0.36***	0.73***	1													
4. Attention	0.38***	0.70***	0.74***	1												
5. Processing speed	0.35***	0.68***	0.68***	0.72***	1											
6. Visual spatial organization	0.36***	0.66***	0.66***	0.68***	0.70***	1										
7. Sustained sequential processing	0.33***	0.68***	0.66***	0.69***	0.70***	0.76***	1									
8. Working memory	0.38***	0.72***	0.73***	0.76***	0.75***	0.70***	0.77***	1								
9. Novel problem solving	0.30***	0.72***	0.65***	0.64***	0.66***	0.70***	0.71***	0.73***	1							
10. Mathematics skills	0.29***	0.58***	0.56***	0.59***	0.60***	0.57***	0.62***	0.66***	0.62***	1						
11. Basic reading skills	0.29***	0.65***	0.58***	0.53***	0.61***	0.64***	0.64***	0.60***	0.71***	0.53***	1					
12. Written expression skills	0.29***	0.66***	0.61***	0.59***	0.64***	0.65***	0.68***	0.65***	0.70***	0.54***	0.76***	1				
13. Effort	0.22***	0.08**	0.09**	0.15***	0.15***	0.07*	0.07*	0.13***	0.03	0.11***	−0.01	0.03	1			
14. Reward	−0.11***	−0.44***	−0.37***	−0.38***	−0.35***	−0.32***	−0.34***	−0.38***	−0.40***	−0.33***	−0.39***	−0.36***	−0.19***	1		
15. Overcommitment	0.17***	0.13***	0.15***	0.14***	0.16***	0.12***	0.12***	0.18***	0.11***	0.15***	0.04	0.08**	0.55***	−0.26***	1	
16. Age	−0.01	−0.02	0.02	0.01	0.01	−0.01	−0.02	−0.02	0.02	−0.01	−0.03	−0.04	−0.02	−0.02	0.01	1
17. Household crowding index	−0.003	−0.001	−0.02	0.001	0.02	−0.001	0.01	0.03	−0.02	0.02	−0.03	−0.03	0.05	0.07*	0.05	0.04

*$p < .05$; **$p < .01$; ***$p < .001$. Numbers in the table refer to Pearson correlation coefficients

Moderation analysis with each LEAF subscales score taken as the dependent variable

The detailed outcomes of the moderation analysis, incorporating effort/reward/overcommitment as moderators in the relationship between noise annoyance and memory/attention/learning, are delineated in Table 5. All results were adjusted over the following variables: age, gender and household crowding index. The interactions noise annoyance by effort was significantly associated with memory function, sustained sequential processing and mathematics skills. The interaction noise annoyance by reward was significantly associated with memory function, attention, processing speed, sustained sequential processing, working memory and mathematics skills, whereas the interaction noise annoyance by overcommitment was significantly associated with factual memory, attention and processing speed (Table 5).

At low levels of effort, higher noise annoyance was significantly associated with worse memory function (Beta = 0.94; p =.002) and mathematics skills (Beta = 0.40; p =.002), whereas at low (Beta = 0.49; p <.001) and moderate (Beta = 0.29; p =.001) levels of effort, it was significantly associated with worse sustained sequential processing (Table 6, Models 1a, 2a and 3a).

At low and moderate levels of reward, higher noise annoyance was significantly associated with worse attention (Beta = 0.48; p <.001 and Beta = 0.20; p <.031 respectively; Model 2b), sustained sequential processing (Beta = 0.43; p <.001 and Beta = 0.22; p =.013 respectively; Model 2d) and working memory (Beta = 0.47; p <.001 and Beta = 0.28; p =.002 respectively; Model 2e). At low levels of reward, higher annoyance was significantly associated with worse memory function (Beta = 0.82; p =.007; Model 2a), processing speed (Beta = 0.38; p =.001; Model 2c) and mathematic skills (Beta = 0.28; p =.026; Model 2f).

Finally, at low and moderate levels of overcommitment, higher noise annoyance was significantly associated with worse factual memory (Beta = 0.49; p <.001 and Beta = 0.25; p =.005 respectively; Model 3a), worse attention (Beta = 0.45; p <.001 and Beta = 0.26; p =.005 respectively; Model 3b) and worse processing speed (Beta = 0.43; p <.001 and Beta = 0.23; p =.012 respectively; Model 3c).

Discussion

Our initial hypotheses were to find a moderating effect of effort, reward and overcommitment between noise annoyance and each LEAF subscale. Some of those hypotheses were confirmed namely the moderating effect of (1) effort between noise annoyance and memory function, sustained sequential processing and mathematics skills, (2) of reward between noise annoyance and memory function, attention, processing speed, sustained sequential processing, working memory and mathematics skills, and (3) of overcommitment between noise annoyance and factual memory, attention and processing speed.

The current study yielded significant findings indicating a solid correlation between noise annoyance and its effects on cognitive performance among adolescents. Our findings demonstrated a strong association between higher noise annoyance and worse cognitive performance pertaining to the memory, learning, attention and overall executive function among adolescents, highlighting the intrinsic difficulties of this vulnerable age group in appropriately assessing threats emanating from stressors, along with their comparatively underdeveloped coping mechanisms relative to adults [28]. Our results align with various studies proposing that noise may impact adolescent's cognitive skills and intellectual capabilities, particularly reading comprehension [53], memory [54], and impaired attention [55]. Furthermore, studies highlight a strong correlation between prolonged noise exposure and increased noise annoyance, reduced reading proficiency, memory function and performance on national standardized tests, in contrast to students unaffected by such auditory disturbances [56, 57]. Suggested mechanisms elucidating the impact of noise on adolescents' cognitive faculties pertain to challenges encountered in communication, impaired attentional processes, increased levels of frustration owing to the effects of noise-induced annoyance as well as the ensuing consequences of disrupted sleep patterns on their overall academic and cognitive performance [25, 28]. Particularly, translational studies highlighted the detrimental effects of noise-induced annoyance on the central nervous system activity through elevated oxidative stress [58–60], imbalance in neurotransmitter levels, impaired cognition and genetic modifications [61–63].

In this study, effort, reward and overcommitment were posited as moderators, exerting an influence on the association between noise annoyance and distinct cognitive domains within Lebanese adolescents. At low levels of effort, reward and overcommitment, outcomes demonstrated consistent uniformity within specific cognitive domains, thereby highlighting that these factors, when experienced by adolescents subjected to noise-induced annoyance, contributed to adverse effects on specific areas of cognitive executive functioning. Analogous findings were observed for moderate levels of overcommitment across defined cognitive faculties. Furthermore, when examining moderate levels of reward, similar findings were demonstrated, exclusively within the specific cognitive domains encompassing attention, working memory and sustained sequential processing; conversely, in the case of moderate levels of effort, comparable results were observed, albeit solely associated with sustained sequential processing. Our findings align with

Table 4 MANCOVA analysis of factors associated with the scores

	Beta	*p*	95% CI	Partial Eta Squared
Model 1: Memory function score as the dependent variable.				
Noise annoyance	0.60	**0.010**	0.15; 1.06	0.005
Age	− 0.09	0.545	− 0.37; 0.20	< 0.001
Household crowding index	− 0.12	0.772	− 0.92; 0.68	< 0.001
Gender (males vs. females*)	− 0.46	0.377	-1.48; 0.56	0.001
Model 2: Comprehension and conceptual learning score as the dependent variable.				
Noise annoyance	0.48	**< 0.001**	0.32; 0.64	0.026
Age	− 0.07	0.206	− 0.17; 0.04	0.001
Household crowding index	− 0.05	0.711	− 0.33; 0.23	< 0.001
Gender (males vs. females*)	− 0.12	0.528	− 0.47; 0.24	< 0.001
Model 3: Factual memory score as the dependent variable.				
Noise annoyance	0.31	**< 0.001**	0.14; 0.48	0.010
Age	0.01	0.849	− 0.10; 0.12	< 0.001
Household crowding index	− 0.14	0.355	− 0.44; 0.16	0.001
Gender (males vs. females*)	− 0.34	0.079	− 0.72; 0.04	0.002
Model 4: Attention score as the dependent variable.				
Noise annoyance	0.32	**0.001**	0.13; 0.50	0.009
Age	0.003	0.963	− 0.11; 0.12	< 0.001
Household crowding index	− 0.04	0.804	− 0.36; 0.28	< 0.001
Gender (males vs. females*)	− 0.17	0.414	− 0.58; 0.24	0.001
Model 5: Processing speed score as the dependent variable.				
Noise annoyance	0.29	**0.001**	0.11; 0.47	0.008
Age	− 0.01	0.917	− 0.12; 0.11	< 0.001
Household crowding index	0.10	0.528	− 0.21; 0.41	< 0.001
Gender (males vs. females*)	− 0.22	0.266	− 0.62; 0.17	0.001
Model 6: Visual spatial organization score as the dependent variable.				
Noise annoyance	0.31	**< 0.001**	0.14; 0.47	0.010
Age	− 0.03	0.618	− 0.13; 0.08	< 0.001
Household crowding index	− 0.02	0.873	− 0.31; 0.27	< 0.001
Gender (males vs. females*)	0.23	0.223	− 0.14; 0.60	0.001
Model 7: Sustained sequential processing score as the dependent variable.				
Noise annoyance	0.32	**< 0.001**	0.15; 0.49	0.011
Age	− 0.06	0.262	− 0.17; 0.05	0.001
Household crowding index	0.05	0.729	− 0.25; 0.35	< 0.001
Gender (males vs. females*)	0.07	0.709	− 0.31; 0.45	< 0.001
Model 8: Working memory score as the dependent variable.				
Noise annoyance	0.40	**< 0.001**	0.22; 0.57	0.015
Age	− 0.08	0.174	− 0.19; 0.03	0.001
Household crowding index	0.13	0.402	− 0.18; 0.45	0.001
Gender (males vs. females*)	− 0.31	0.131	− 0.70; 0.09	0.002
Model 9: Novel problem solving score as the dependent variable.				
Noise annoyance	0.43	**< 0.001**	0.27; 0.60	0.020
Age	0.01	0.842	− 0.09; 0.11	< 0.001
Household crowding index	− 0.16	0.287	− 0.45; 0.13	0.001
Gender (males vs. females*)	0.13	0.509	− 0.25; 0.50	< 0.001
Model 10: Mathematics skills score as the dependent variable.				
Noise annoyance	0.21	**0.026**	0.03; 0.40	0.004
Age	− 0.06	0.347	− 0.17; 0.06	0.001
Household crowding index	0.11	0.509	− 0.22; 0.44	< 0.001
Gender (males vs. females*)	− 0.52	**0.014**	− 0.94; − 0.11	0.005
Model 11: Basic reading skills score as the dependent variable.				
Noise annoyance	0.36	**< 0.001**	0.17; 0.54	0.012
Age	− 0.06	0.276	− 0.18; 0.05	0.001

Table 4 (continued)

	Beta	*p*	95% CI	Partial Eta Squared
Household crowding index	− 0.21	0.194	− 0.53; 0.11	0.001
Gender (males vs. females*)	0.31	0.138	− 0.10; 0.71	0.002
Model 12: Written expression skills score as the dependent variable.				
Noise annoyance	0.30	**< 0.001**	0.14; 0.47	0.010
Age	− 0.08	0.161	− 0.18; 0.03	0.002
Household crowding index	− 0.18	0.232	− 0.47; 0.12	0.001
Gender (males vs. females*)	0.24	0.215	− 0.14; 0.61	0.001

*Reference group; Numbers in bold indicate significant *p* values

Table 5 Moderation analysis taking noise annoyance as the independent variable, effort/reward/overcommitment as moderators and memory/attention/learning scores as dependent variables

	Beta	t	*p*	95% CI
Model 1: Effort as the moderator				
Memory function	− 0.14	-2.81	**0.005**	− 0.24; − 0.04*
Comprehension and conceptual learning	0.01	0.42	0.673	− 0.03; 0.04
Factual memory	− 0.03	-1.77	0.078	− 0.07; 0.004
Attention	− 0.03	-1.27	0.205	− 0.07; 0.01
Processing speed	− 0.03	-1.67	0.096	− 0.07; 0.01
Visual spatial organization	− 0.02	-1.08	0.283	− 0.06; 0.02
Sustained sequential processing	− 0.05	-2.42	**0.016**	− 0.08; − 0.01*
Working memory	− 0.01	− 0.60	0.552	− 0.05; 0.03
Novel problem solving	− 0.03	-1.72	0.085	− 0.07; 0.01
Mathematics skills	− 0.06	-2.71	**0.007**	− 0.10; − 0.02*
Basic reading skills	− 0.02	-1.18	0.240	− 0.06; 0.02
Written expression skills	− 0.01	− 0.68	0.497	− 0.05; 0.02
Model 2: Reward as the moderator				
Memory function	2.71	2.69	**0.007**	0.73; 4.68*
Comprehension and conceptual learning	− 0.01	− 0.95	0.343	− 0.03; 0.01
Factual memory	− 0.02	-1.86	0.064	-04; 0.001
Attention	− 0.04	-3.33	**0.001**	− 0.07; − 0.02*
Processing speed	− 0.03	-2.56	**0.011**	− 0.05; − 0.01*
Visual spatial organization	− 0.004	− 0.37	0.715	− 0.03; 0.02
Sustained sequential processing	− 0.03	-2.67	**0.008**	− 0.05; − 0.01*
Working memory	− 0.03	-2.34	**0.020**	− 0.05; − 0.004*
Novel problem solving	− 0.02	-1.61	0.109	− 0.04; 0.004
Mathematics skills	− 0.03	-2.14	**0.032**	− 0.05; − 0.002*
Basic reading skills	− 0.004	− 0.31	0.755	− 0.03; 0.02
Written expression skills	− 0.01	-1.17	0.242	− 0.04; 0.01
Model 3: Overcommitment as the moderator				
Memory function	− 0.07	− 0.91	0.364	− 0.21; 0.08
Comprehension and conceptual learning	− 0.02	− 0.78	0.439	− 0.07; 0.03
Factual memory	− 0.08	-3.00	**0.003**	− 0.14; − 0.03
Attention	− 0.07	-2.19	**0.029**	− 0.12; − 0.01*
Processing speed	− 0.07	-2.43	**0.015**	− 0.13; − 0.01*
Visual spatial organization	− 0.003	− 0.13	0.899	− 0.06; 0.05
Sustained sequential processing	− 0.05	-1.76	0.079	− 0.10; 0.01
Working memory	− 0.05	-1.70	0.090	− 0.11; 0.01
Novel problem solving	− 0.04	-1.57	0.117	− 0.10; 0.01
Mathematics skills	− 0.06	-1.94	0.053	− 0.12; 0.001
Basic reading skills	− 0.01	− 0.46	0.644	− 0.07; 0.05
Written expression skills	− 0.04	-1.51	0.132	− 0.10; 0.01

*indicates significant moderation; numbers in bold indicate significant *p* values; results adjusted over age, gender and household crowding index

Table 6 Conditional effects of the focal predictor (noise annoyance) at values of the moderators

	Beta	t	*p*	95% CI
Model 1: Effort as the moderator				
Model 1a: Memory function as the dependent variable.				
Low (=12.48)	0.94	3.06	**0.002**	0.34; 1.54
Moderate (=16.63)	0.35	1.52	0.129	−0.10; 0.80
High (=20.78)	−0.24	−0.76	0.450	−0.86; 0.38
Model 2a: Sustained sequential processing as the dependent variable.				
Low (=12.48)	0.49	4.16	**<0.001**	0.26; 0.71
Moderate (=16.63)	0.29	3.35	**0.001**	0.12; 0.47
High (=20.78)	0.10	0.85	0.398	−0.13; 0.34
Model 3a: Mathematics skills as the dependent variable.				
Low (=12.48)	0.40	3.12	**0.002**	0.15; 0.65
Moderate (=16.63)	0.16	1.70	0.089	−0.03; 0.35
High (=20.78)	−0.07	−0.56	0.578	−0.33; 0.19
Model 2: Reward as the moderator				
Model 2a: Memory function as the dependent variable.				
Low (=25.37)	0.82	2.69	**0.007**	0.22; 1.42
Moderate (=32.30)	0.31	1.31	0.190	−0.15; 0.76
High (=39.22)	−0.21	−0.64	0.520	−0.85; 0.43
Model 2b: Attention as the dependent variable.				
Low (=25.37)	0.48	3.97	**<0.001**	0.25; 0.72
Moderate (=32.30)	0.20	2.16	**0.031**	0.02; 0.38
High (=39.22)	−0.08	−0.64	0.524	−0.34; 0.17
Model 2c: Processing speed as the dependent variable.				
Low (=25.37)	0.38	3.22	**0.001**	0.15; 0.61
Moderate (=32.30)	0.17	1.89	0.060	−0.01; 0.35
High (=39.22)	−0.04	−0.33	0.745	−0.29; 0.21
Model 2d: Sustained sequential processing as the dependent variable.				
Low (=30.09)	0.43	3.76	**<0.001**	0.21; 0.65
Moderate (=36.00)	0.22	2.49	**0.013**	0.05; 0.39
High (=41.90)	0.004	0.04	0.971	−0.23; 0.24
Model 2e: Working memory as the dependent variable.				
Low (=30.09)	0.47	3.98	**<0.001**	0.24; 0.71
Moderate (=36.00)	0.28	3.07	**0.002**	0.10; 0.46
High (=41.90)	0.08	0.67	0.51	−0.16; 0.33
Model 2f: Mathematics skills as the dependent variable.				
Low (=30.09)	0.28	2.22	**0.026**	0.03; 0.52
Moderate (=36.00)	0.09	0.95	0.342	−0.10; 0.28
High (=41.90)	−0.10	−0.72	0.469	−0.36; 0.17
Model 3: Overcommitment as the moderator				
Model 3a: Factual memory as the dependent variable.				
Low (=6.16)	0.49	4.29	**<0.001**	0.27; 0.71
Moderate (=9.09)	0.25	2.82	**0.005**	0.08; 0.42
High (=12.02)	0.002	0.01	0.990	−0.24; 0.25
Model 3b: Attention as the dependent variable.				
Low (=6.16)	0.45	3.69	**<0.001**	0.21; 0.69
Moderate (=9.09)	0.26	0.09	**0.005**	0.08; 0.44
High (=12.02)	0.07	0.52	0.605	−0.19; 0.33
Model 3c: Processing speed as the dependent variable.				
Low (=6.16)	0.43	3.66	**<0.001**	0.20; 0.66
Moderate (=9.09)	0.23	2.52	**0.012**	0.05; 0.40
High (=12.02)	0.02	0.18	0.860	−0.23; 0.28

Values displayed in bold denote significant *p*-values studies indicating that the decreased cognitive efficiency due to noise interference might not only induce stress but also provoke enduring cognitive fatigue, stemming from the ineffective attempts to cope with noise and the ensuing decline in the engagement of cognitive faculties; the detrimental effects of noise on task performance being greater for adolescents whose cognitive faculties are still developing [15]. Consequently, the decreased effort exerted due to cognitive fatigue considerably impact academic outcomes, leading to an overall decline in quality of life, withdrawal from social engagements and depressive symptoms [64].

Within this context, increased effort, reward and overcommitment become imperative for the execution of tasks among individuals who experience noise-induced annoyance, arising from the need to mitigate and counteract the disruption imposed upon cognitive processes by the auditory interference [65]. Accordingly, our results revealed that at high levels of effort, reward and overcommitment, no statistically significant influence was observed in the relationship between noise annoyance and the collective scope of studied cognitive domains.

Overall, the preceding observations accentuate the inherent interplay between the cognitive, motivational and emotional effects of noise. The investigation of the impact of noise-induced annoyance on cognitive performance among the adolescent demographic is gradually eliciting increasing scientific interest within the corpus body of research, primarily due to the growing concern over mounting levels of noise pollution [74, 78]. In this context, the efficacy of the task performance in the presence of noise is contingent upon various factors, encompassing the specific attributes of noise annoyance which is determined by three major factors according to Stallen [66]: subjective disturbance, perceived control and adaptive capacity for coping with noise annoyance [67]. First, perceived disturbance is related to noise annoyance both directly [66] and indirectly [68] and depends on attributes of the originating noisy source as well as a primary cognitive-emotional appraisal mechanism according to Lazarus' theory of stress and coping [69]. Second, perceived control was suggested to be the primary non-acoustical factor contributing to noise-induced annoyance, according to Stallen [66], and is a component that exerts an impact on annoyance through an alternative mechanism [69]. Last but not least, noise annoyance was found to be a prerequisite for coping which is deemed as a reappraisal of an individual's surroundings [68, 69]. In accordance with the transactional model of stress and coping proposed by Lazarus and Folkman, coping strategies may be characterized as dynamic and adaptive efforts exerted by individuals to manage available resources in response to the stressful transaction, and are subsequently perceived as taxing or surpassing the individual's capabilities and resources [6].

When coping strategies prove to be ineffective, indicating that the perceived threat posed by noise surpasses the available internal or external resources to confront the threat, such as perceived control as well as coping capacity, psychological stress emerge in the form of noise annoyance reactions will arise and cognitive fatigue takes hold [47]. In relation to noise, pivotal considerations entail the potential of an individual to either turn off the noise, or perceiving the capacity to do so, as well as the conviction in one's ability to effectively execute a task in the presence of noise [47]. Should an individual experiencing a noise-induced annoyance harbor the belief that their competence (internal attribution) for task achievement amid noisy conditions is deficient, the likelihood of encountering failure rises, thereby decreasing expectancies for control and increasing susceptibility to helplessness [47]. In this context, the perception of control over the noise serves to attenuate the anticipated threat posed by the noise and concurrently reduces the belief in its potential harm. Moreover, engaging in active coping strategies in response to noise may effectively alleviate and mitigate any adverse consequences [31].

Accordingly, incorporating the functions of effort, reward and overcommitment as moderating variables offers valuable insights into how psychosocial work factors influence the relationship between noise-induced annoyance and cognitive performance in adolescents. These findings can inform clinical practice and guide targeted interventions designed to address both noise-induced annoyance and psychosocial factors, thus preventing the emergence of adverse cognitive outcomes among adolescents. Potential interventions include the implementation of noise control measures such as improving sound insulation in schools, strategically organizing classrooms in quieter areas and adjusting class schedules to mitigate noise exposure. Furthermore, numerous studies suggest the benefits of structured relaxation techniques in educational settings to cope with noise-induced annoyance. These practices not only serve as de-stressing mechanisms but also promote enhanced focus and mental resilience [70]. For example, implementing regular breaks, along with guided meditation sessions or mindfulness practices in designated "meditation rooms" can significantly enhance sensory awareness, facilitate recovery from auditory distractions and improve concentration levels [70–72]. In fact, research has proven that relaxation techniques such as mindfulness and meditation not only sharpen students' cognitive abilities, thereby increasing academic engagement, but also foster emotional balance and resilience [71–73].

Continuous evaluation of these strategies is essential to ensure their effectiveness in reducing noise-related cognitive impairments in adolescents.

Limitations

This study was subject to several limitations. A notable limitation to this study originates from the restricted applied framework of the environmental health determinants, within the examination of the noise annoyance influence on cognitive functioning. In fact, evidence suggests that air pollution may moderate or mediate the relationship between noise-induced annoyance and cognitive functioning across the life course [74]. Moreover, studies discovered a propensity for the simultaneous presence and accumulation of multiple environmental stressors (noise, light pollution, air pollution, psychosocial stress) within residential areas, along with additional stressors, including litter, debris and dirt, that might contribute to adverse health outcomes among adolescents [74, 75]. These findings further underscore the necessity to conduct future large-scale exposome studies that incorporate a comprehensive array of environmental health determinations and develop comprehensive models to steer prospective research investigations [75–77]. We did not ask about the area of living (rural vs. urban), which predisposes us to a residual confounding bias.

Moreover, future research should consider the applied noise as a comprehensive attribute, encompassing both qualitative and quantitative characteristics, which encompasses, in addition to the duration of noise exposure, the mean sound pressure levels and their frequencies [78]. Indeed, systematic reviews have revealed variations in evidence regarding each noise source individually, with the strength of evidence being more pronounced for certain noise sources compared to others [15]. In fact, studies have shown that adolescents reported diverse levels of annoyance depending on the nature of the auditory stimuli, highlighting the necessity for additional research to elucidate the different effects of distinct noise-inducing sources [78]. Consequently, given that noise annoyance is an inherently subjective appraisal reaction subject to individual variation, depending on the specific noise source, a comprehensive assessment of noise-induced annoyance and its implications requires a distinct assessment of every individual source of noise. The inclusion of noise source characteristics in research studies is necessary to facilitate precise discrimination between effects attributable solely to the stimuli and those modulated by subjective determinants [79]. Therefore, the lack of incorporation of personal attributes including negative affectivity, noise sensitivity and personality traits within the study framework raises the possibility of confounding effects arising from these factors [80].

Conclusion

In conclusion, the results of this current study offer solid evidence revealing a statistically significant association between noise annoyance and cognitive performance within the Lebanese adolescent demographic. In addition, it confirms the role of the psychosocial work aspects (effort/reward/commitment) as moderators in the relationship between noise-induced annoyance and cognitive performance among adolescents. Prospective human and animal research studies are warranted to investigate specific biomarkers of oxidative stress as well as the involvement of stress-related hormonal pathways in the noise-mediated stress responses, providing a quantitative measure of the extent of the adverse health effects attributed to noise-induced annoyance. These research initiatives hold the potential to offer valuable insights into the neurobiological and physiological mechanisms underlying the adverse health implications of noise-induced exposure, which could potentially contribute to cognitive impairment among adolescents. Ultimately, this advanced knowledge can serve as a solid foundation for clinicians and researchers for the development of targeted public health strategies and tailored interventions designed specifically for the adolescent population.

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Author contributions
Vanessa Azzi and Souheil Hallit designed the study; Diana Malaeb, Sami El-Khatib, Mariam Dabbous and Fouad Sakr collected the data; Nohad-Maria Azzi drafted the manuscript; Souheil Hallit conducted the analysis and interpreted the results; Rabih Hallit, Diana Malaeb and Sahar Obeid reviewed the paper for intellectual content; all authors reviewed the final manuscript and gave their consent.

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Data availability
The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author on a reasonable request.

Declarations

Ethics approval and consent to participate
The Lebanese International University Ethics and Research Committee approved this study protocol (2023RC-017-LIUSOP). Participants were asked to get their parents' approval before filling the survey; an electronic informed consent was considered obtained from each participant when submitting the online form. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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