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ORIGINAL RESEARCH ARTICLE
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Vision Payment Claims Analyses with Health Insurance

AARON HOUSTON MPH[1], JOSEPH RUSKIWEWICZ, OD, MPH[2], JOHN GAAL MHA[2], CHAITALI BAVISKAR MHSA[2], ATIYA LATIEMR[2]
[1]College of Public Health, Temple University
[2] College of Optometry Eye Institute, Salus University Oak Lane Campus

Correspondence: aaron.houston@temple.edu (Aaron L. Houston)

The purpose of this study was to identify associations between insurance type and out-of-pocket costs to zip code and income level. This was a cross-sectional study, using secondary data analyses. The study was completed at The Eye Institute (TEI) East Oak Lane Campus in Philadelphia, PA. The study population was all patients seen at TEI East Oak Lane Campus, from January 1st, 2019, to December 31st, 2019, whose encounter generated an insurance claim (n=68,484). The exposure was insurance type, and the outcome was out-of-pocket costs. Data analyses were performed using SAS, version 9.4. In all statistical analyses, p-values were one-sided and considered statistically significant if 0.05 or lower. The study protocol was approved by the Institutional Review Boards of Salus University. The sample represented an older population with an average age of about 55. There was a significant association found between insurance type and out-of-pocket costs (p<0.0001). People with managed Preferred Provider Organization (PPO) pay the least, while those on Medicaid and Workers' Compensation pay the most out of pocket. 12 zip codes were studied. The two Philadelphia zip codes which pay the most out of pocket have two of the lowest average household incomes. Out-of-pocket expenses vary by insurance type with lower-income zip codes paying more which can potentially have a negative effect on patient vision health and access to care. These findings contribute to the identification of variables that influence an individual's healthcare and evidence for opportunities to improve insurance coverage accessibility.

Keywords*: affordability, claims, healthcare, insurance, vision*

Introduction

There are 31 million underinsured Americans who do not make enough income to pay for their medical expenses.[1] This means they cannot afford to pay for prescribed treatments, to pay for recommended tests, or to avoid going into debt over medical bills. A person is considered underinsured if out-of-pocket health care costs exceed ten percent of their income[1]. Health insurance that provides more extensive coverage of preventive and screening services is likely to result in greater and more appropriate use of these services by patients.[2] In 2017, more than 93 million US adults were at high risk for vision loss compared with almost 65 million in 2002.[10]. However, only 56.9% visited an eye care professional annually, and only 59.8% received a dilated eye examination. Among adults who reported needing eyeglasses, approximately 9% said they could not afford them, up slightly from 2002.[10]

The overall estimated morbidity of uncorrectable visual impairment in the U.S.

population among individuals ages 40 and older was 2.14%. [12] Deaths can be related specifically to vison-related disease or infection complications. In Siantar's 2015 study, the relationship between visual impairment and age-related eye diseases with mortality was studied. They concluded that diabetic retinopathy and retinal vein occlusion were markers of cardiovascular disease and associated with increased cardiovascular disease mortality.[11] This suggests that visual impairment can be a predictor for chronic diseases such as cardiovascular disease.

Moreover, there are barriers present that influence individual's healthcare coverage. such as employment status, transportation to clinics that accept certain insurance, and cost of insurance/ healthcare services. Also, not all employers offer vison benefits. Employment status is a factor since the cost of eye care may be non-trivial for low-or no-income adults suggesting that having vision insurance may increase the use of care substantially and the overall health of the patient[3]. The average annual deductible for single, individual coverage is $4,364 and $8,439 for family coverage.[16] Indeed, the average deductible or employer coverage has grown seven times faster than workers' wages since 2010[5]. Vision coverage is currently an add-on benefit, which is often not covered by employment-based health insurance plans, and one of the first benefits to be eliminated to lower health insurance costs[7]. However, vision loss and impairment have been tied to several other health complications and co-morbidities. According to the Centers for Disease Control and prevention[4], people with vision loss are more likely to report depression, diabetes, hearing impairment, stroke, falls, cognitive decline, and premature death. These all may play a role in the type of coverage one can get and the risks of higher payment costs in comparison to others without preexisting conditions.

According to a study by Winkelman[13], enrollment in Medicaid, a government-funded program that covers health care costs for low-income individuals and families in the United States, increased from 35 million to over 74 million between 2000 and 2017[3]. However, it should be noted that not every state offers the same coverage for vision. Still, enrollment in Medicaid was associated with significant increases in total medical spending and reductions in out-of-pocket costs, higher levels of prescription medication use, and improvements in access to care relative to individuals who remained uninsured[14]. The Patient Protection and Affordable Care Act (ACA), significantly increased Medicaid enrollment in some states and not others, creating natural experiments to study the population-level impact of Medicaid. A large body of evidence stemming from these experiments suggests Medicaid has positive effects on access to care, health, and financial security[13].

In this study, financial class consisted of 22 different insurance types. Vison, the financial class with the highest frequency of claims, reflected only Medicaid Managed Care claims. It consisted of a combined group of insurers such as Davis vision, EyeMed, Vision benefits of America, UHC, Aetna, Cigna National Vision Administrator and HealthPartners. Age and race acted as moderating variables for whether a stronger relationship was present. Income level was the mediating variable and was ranked lowest to highest by zip code. The 12 chosen zip codes had the highest number of claims to study.

Materials and Methods

This was a cross-sectional study: using a secondary data analysis. The study was completed at The Eye Institute (TEI) East Oak Lane Campus in Philadelphia, PA for approximately nine months from August 2020-April 2021. The study population was all patients seen at TEI East Oak Lane Campus, specifically patients seen at TEI clinic from January 1st, 2019, - to December 31st, 2019, whose encounter generated an insurance claim (n=68,484). Inclusion criteria were patients who came in for a visit. The exposure was insurance type and outcomes were patient total amount, billed amount, and payment amount by patient. The study protocol was approved by the Institutional Review Boards of Salus University.

Data analyses were performed using SAS, version 9.4 [9]. In all statistical analyses, p-values were one-sided and considered statistically significant if 0.05 or lower. Patient amount, billed amount and pay amount were the dependent variables. From the acquired data, the statistical analysis included logistic regression and ANOVA-comparison between the insurance types using chi-square test was performed for associations between insurance type and costs. The primary dependent variables were patient total amount ($p<0.0001$), billed amount, ($p<0.0001$), and payment amount, ($p<0.0001$). Other descriptive variables, such as race, age, and sex, compiled subject characteristics were used in analyses. Overall, analyses examined the claim amounts by the financial class at TEI East Oak Lane branch in Philadelphia to determine a relationship between out-of-pocket costs and income. This research applies towards the public health implications of possible variables which influence individuals' healthcare accessibility and affordability.

Results

Table 1 reports the descriptive statistics by age, sex, race, and financial class of claims reported at TEI from January 1st, 2019 – to December 31st, 2019. Overall, the sample represented an older population with an average age of about 55. Most of the claims were generated by Black people (80.3%) and the majority female (62.8%). The highest frequency of claims came from the vision class as mentioned in the table (38.63%). The second-highest number of

Table 1.
Descriptive Statistics by age, sex, race, and financial class of claims reported at TEI from January 1st, 2019 – December 31st, 2019.

	Total N (%)
Total	68484
Age (Mean ± Std Dev)	54.87 ± 24.32
Sex	
Female	43019 (62.84%)
Male	25426 (37.14%)
Unknown	11 (.02%)
Missing	28
Race	
Black	52672 (80.3%)
Other	5362 (8.1%)
White	5162 (8%)
Declined to say	1249 (1.9%)
Asian	784 (1.12%)
American Indian or Alaska	216 (.33%)
Hawaiian	167 (.25%)
Missing	2902
Financial Class	
Vision	26442 (38.63%)
Blue Cross	14480 (21.15%)
Medicare	13042 (19.05%)
Commercial	4675 (6.83%)
Managed Medicare	2393 (3.50%)
Medicaid	2195 (3.21%)
No Insurance Adj	1198 (1.75%)
Grant	1075 (1.57%)
Invoice Billing	1044 (1.53%)
BCBS PPO	324 (.47%)
Self-Pay	320 (.47%)
Student Benefits	317 (.46%)
Grant-Low Vision	305 (.45%)
School Program	190 (.28%)
Employee Benefit	153 (.22%)
Work Comp	90 (.13%)
Medical Records	74 (.11%)
Auto (MVA)	51 (.07%)
Managed HMO	43 (.06%)
Other	27 (.04%)
Managed PPO	18 (.03%)
Missing	28

claims came from Blue Cross (21%). Medicare is third, covering 19% of the claims generated. Overall, those three categories of insurers covered approximately 80% of the insurance claims

generated. In each of the ANOVA tests (Table 2), there is a significant association between financial class, patient amount, billed amount, and payment amount. No correlations were run. Equally, the F values show that there was a significant difference as well.

In detail, Table 3 breaks down the average patient number of clams by financial class by a means analysis. As shown, those on a Managed PPO paid the least, followed by those with Other, while those with Workers Compensation and Medicaid paid the most out of pocket. The second highest paying out-of-pocket insurance type is Medicaid. However, Vision class patients pay

significantly less on average that Medicaid patients. Again, Vision (38.63%) is used to reflect only Medicaid Managed Care as

Table 2.
One-Way Analysis of Variance (ANOVA) by financial class of patient amount, billed amount, and payment amount.

Dependent Variables	Mean ± Std Dev	Source	Sum of Squares	DF	Mean of Squares	One-Way ANOVA
					F	P-value
Patient Amount	$1.23 ± $15.44	Financial Class	149116.27	20	7455.81	31.57
Billed Amount	$111.05 ± $100.76	Financial Class	11407199.3	20	570360	57.10
Pay Amount	-$34.84 ± $52.09	Financial Class	15751152.8	20	787557.6	316.97

**A negative amount represents dollars received.*
** The patient amount variable is the amount paid by the patient out of pocket.*
**The billed amount is the total amount billed for the service.*
**Pay amount is the amount that was paid in total by the financial class and patient.*

Table 3.
Average patient amount by financial class

Financial Class	Total Claims	Mean ± Std Dev	Minimum Claim Amount	Maximum Claim Amount
Vision	26442	$0.8888889 ± $15.7247147	-$405.0000000	$450.0000000
Blue Cross	14480	$0.5365331 ± $13.8018164	-$265.0000000	$325.0000000
Medicare	13042	$1.6097224 ± $12.4053521	-$155.0000000	$258.0000000
Commercial	4675	$2.8188235 ± $20.4654626	-$100.0000000	$549.0000000
Managed Medicare	2393	-$0.1512746 ± $16.3376430	-$166.0000000	$147.0000000
Medicaid	2195	$7.4236902 ± $25.7403943	-$67.0000000	$211.0000000
No Insurance Adj	1198	-$0.4766277 ± $15.4377194	-$300.0000000	$140.0000000
Grant	1075	0 ± 0	0	0
Invoice Billing	1044	-$0.1024904 ± $1.9381702	-$40.0000000	0
BCBS PPO	324	$4.8487654 ± $29.7136796	-$171.0000000	$128.0000000
Self-Pay	320	0.5312500 ± 15.9483578	-$158.0000000	$118.0000000
Student Benefits	317	0 ± 0	0	0
Grant-Low Vision	305	0 ± 0	0	0
School Program	190	0 ± 0	0	0
Employee Benefit	153	$1.9150327 ± $14.0154744	0	$115.0000000
Work Comp	90	$16.0666667 ± $32.6482100	0	$188.0000000
Medical Records	74	0 ± 0	0	0
Auto (MVA)	51	0 ± 0	0	0
Managed HMO	43	$3.7674419 ± $9.4964585	0	$29.0000000
Other	27	-$4.8148148 ± $15.7895706	-$48.0000000	$14.0000000

**Financial Class is insurance type.*

payer. So, those who patients who receive Medicaid benefits through a Managed Care Plan pay less on average than patients who have plain Medicaid (3.21%) at TEI.

Table 4 shows the top Philadelphia zip codes by average patient amount, payment amount. Claims by people who resided in 19140 paid the most on average out of pocket, followed by those in 19124, while those in 19119 and 19132 paid the least.

average household incomes in comparison to the rest of the zip codes listed. As shown, the zip codes that have the highest-ranked average patient amounts include 19140, 19124, and 19120. The zip codes with the lowest-ranked average household income are 19132, 19140, and 19144.[15] The zip code with the lowest average income, 19132, paid the lowest on average out of pocket, ($.77 ± $14.57). While the zip code with the second

Table 4.
The top patient zip codes on claims by average patient amount and payment amount.

Zip Code	Patient Amount	Pay Amount	Total claims
19140	$2.71 ± $19.60	-$33.02 ± $46.69	3356
19124	$2.27 ± $16.21	-$34.80 ± $58.90	1913
19120	$1.77 ± $14.49	-$31.70 ± $44.86	6402
19126	$1.46 ± $17.78	-$33.29 ± $38.93	3769
19138	$1.37 ± $14.8	-$33.37 ± $43.03	7086
19111	$1.25 ± $16.46	-$31.55 ± $40.68	2283
19150	$1.18 ± $15.58	-$34.28 ± $36.96	5221
19144	$1.09 ± $12.76	-$33.63 ± $46.52	4312
19141	$1.08 ± $12.99	-$33.56 ± $41.44	6677
19119	$.77 ± $16.28	-$38.92 ± $66.19	2447
19132	$.77 ± $14.57	-$35.15 ± $49.19	1885
19149	$.99 ± $12.66	-$33.09 ± $46.00	1318

Table 5 ranks zip codes by patient amount, highest to lowest, and avg household income, least to greatest, and shows how they align with each other. However, those zip codes that paid the most on average for patient amounts also had two of the lowest

lowest average income 19140, paid the most out of pocket on average ($2.71 ± $19.60).

To summarize, there was a significant association found between financial class with patient total amount ($p<0.0001$), billed amount($p<0.0001$), and

Table 5.
Ranks the amount paid and the avg household income to demonstrate how they align with each other. Average household income data from 2009-2013 was taken from the Philadelphia Inquirer.

Zip Code	Patient Amount Rank*	Avg Household Income Rank**
19140	1	2
19124	2	4
19120	3	7
19126	4	8
19138	5	6
19111	6	10
19150	7	11
19141	8	5
19144	9	3
19149	10	9
19119	11	12
19132	12	1

** - ranked highest to lowest amount paid by the patient*
*** - ranked lowest to highest average household income*

pay amount ($p<0.0001$). People with managed PPO paid the least, while those on Medicaid and workers' compensation paid the most out of pocket. The two Philadelphia zip codes which paid the most out of pocket had two of the lowest average household incomes in the Greater Philadelphia area. If Vision (39%) is used to report only Medicaid Managed Care as payor, can contrast the out-of-pocket expense for this group of Medicaid patients vs. the straight Medicaid patients [3.21% of claims]).

Discussion

The study intended to measure associations, if any, between insurance type, out-of-pocket costs, and income of individuals' access to adequate coverage. The hypothesis was that there would be a direct relationship between income and out-of-pocket costs. For example, as out-of-pocket costs went up, the patient's income would go up and vice versa. Total out-of-pocket health care costs can vary depending on the service billed and type of health insurance coverage, employment, income, age of the patient. All are viable factors in determining one's health insurance coverage and overall charges, therefore influencing out-of-pocket costs as well.

A significant association was found between financial class and out-of-pocket costs by the patient at TEI Oak Lane campus. Individuals with Workers Compensation, a form of insurance that provides medical expense costs to employees and families of employees who are injured, sick, or are killed on the job, are paid the most out of pocket in the total paid amount. Medicaid, government insurance for low-income individuals and households, paid the second most out of pocket in total patient costs. Again, these are individuals who had only Medicaid and are not enrolled in a managed care plan. Medicaid. There may be incentive for patients to select a Medicaid Managed Care Plan vs. Medicaid if there is a significant difference in out-of-pocket costs. These insurance types represent disabled and impoverished groups who tend to lack access to affordable and adequate health insurance. Among a national sample of uninsured individuals, Medicaid enrollment was associated with substantial favorable changes in out-of-pocket costs, prescription drug use, and access to care. Winkelman[13] findings suggest Medicaid is an important tool to reduce insurance-related disparities among Americans [14]. Of course, it would be expected that these individuals would pay the least amount of money as compared to other insurance types in out-of-pocket costs. However, as presented in the results, this is not the case. This implies that the lowest income households do not always pay the lowest out-of-pocket expenses.

Evidence linking specific features of neighborhood social environments to health outcomes and insurance accessibility is more difficult to summarize than evidence for the effects of physical environments on health. From 1999 to 2008, individuals with less education and lower income were consistently less likely to have had an eye care visit in the past 12 months compared with their counterparts. During this period, the inability to afford needed eyeglasses increased among non-Hispanic whites and those with high school education[14]. The TEI serves a diversity of patients between its many clinic locations throughout the city of Philadelphia. Generally, most of the insurance claims generated during the study period were by Black people and women. This could be due to only one clinic location being included in the study and the location of the clinic being in a majority Black residential and low-income area. It is possible that if the study were to include multiple years and different clinic locations, the diversity and socioeconomic status of the results would be different, suggesting that the location is a potential effect modifier in the results. Even so, the results suggest that the type of health insurance is significantly associated with total out-of-pocket costs for the patient.

Also, insurance type and out-of-pocket expenses seem to be different depending on the income of the patient and their race. The three Philadelphia zip codes with the highest total amount paid by the patient, had three of the lowest average household incomes. Uniformly low socioeconomic status, coupled with a high proportion of minorities (86% of the sample) indicates a sample that would expect to be at greatly increased risk for blindness and visual impairment compared to the general population[1]. During the observed 12-month study, most of the payment claims were from Black patients; nonetheless, there is still no reason for them to pay the most on average inpatient amount. Excess payment with the inability to pay put a greater financial burden on already working low-income people and influences accessibility which affects the health of Philadelphians. America recognizes now more than ever that racism and discrimination are deeply ingrained in the social, political, and economic structures of our society. For minorities, these differences result in unequal access to quality education, healthy food, livable wages, and affordable insurance[8].

Limitations

The study has several limitations that should be considered in the interpretation of the results. The biggest limitation is that the Vison Financial class composition includes many patients with a Medicaid Managed Care Plan which misses patients not classified in the Medicaid or Managed Medicare class category. Also, TEI has several clinics across the Philadelphia area. The analyses used only one clinic in a predominantly Black residential area that provided a homogenous group that limits the ability to identify the potential impact race of and income relative to mainstream communities. It is therefore notable that among persons from the same communities and of similar socioeconomic status, race and ethnicity are not significant differentiating factors between these two groups. Also, the brevity of the data collection period limited the number of claims that were able to be observed and analyzed over the chosen study period.

Conclusion

Overall, the study results suggest several implications for public health. The clinical relevance of these findings identifies variables, such as zip code, income and employment that influence healthcare costs and evidence for opportunities to improve insurance coverage affordability. In some cases, lower average household income zip codes tend to pay more out of pocket for health insurance in comparison to higher income households. There should be more federal and local policy put in place to help assist health insurance costs since it has been shown to be beneficial over the years. Also, the insurance enrollment requirements should be broader to increase accessibility among the population, and it should cover more eye care services

Conflicts of Interest
The authors have no conflicts to disclose.

Statement of Contributions
Aaron Houston conceived the idea for this study, study design, data analysis, data organization and drafted the manuscript. Joseph Ruskiwewicz helped conceive the idea for this study. John Gaal assisted with data analysis, and provided input on all aspects of the manuscript. Chaitali Baviskar and Atiya Latimer analyzed and organized the data.

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ORIGINAL RESEARCH ARTICLE
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ADHD and DIRAS Single Nucleotide Polymorphism as an Indicator of Prolonged Concussion Recovery

TAZIAH KENNEY[1] JANE MCDEVITT[2]
[1]College of Life Sciences, Jefferson University
[2]Department of Health and Rehabilitation Sciences, College of Public Health, Temple University

Correspondence: Kenney.Taziah@gmail.com (Taziah Kenney)

Context: *The purpose of this study was to determine the association between the presence of a single nucleotide polymorphism (SNP; rs1412005) within the promoter region of DIRAS2 (i.e., a gene associated with ADHD) and the association with prolonged recovery following a sport-related concussion.* ***Methods:*** *We implemented a case-control study, where cases and controls were selected from a cohort of 117 deidentified concussed athletes (70% male, 20+5.22 y/o; 21 different sports). Eleven samples from this patient cohort conveyed a self-reported diagnosed ADHD and were age and sex-matched to 22 participants with no self-reported ADHD diagnoses. The DNA from saliva samples was extracted, estimated, and genotyped using real-time polymerase chain reaction.* ***Results:*** *The average recovery time for the case group was 21.50 days (SD=13.96), while the average recovery time for the control group was 15.66 days (SD= 8.50). We found that individuals with ADHD were 5 times more likely to have prolonged recovery than their non-ADHD counterparts (CI= .95). Also, the authors found that only 13.6% of the individuals without an ADHD diagnosis recovered in > 30 days (p=0.044). Additionally, the authors found that 72.7% of the carriers of the T allele (i.e., minor allele) recovered in greater than 30 days (p=0.213).* ***Conclusion:*** *Researchers concluded that individuals with ADHD had a higher risk of prolonged concussion recovery lasting greater than 30 days. Also, carrying the rare allele was associated with prolonged recovery, which suggests this SNP could be a potential genetic marker for both prolonged concussion recovery and the presence of ADHD.*

Keywords*: ADHD, concussion, genetic variation, concussion recovery*

Concussion Recovery

Ten percent of the population has an attention deficit hyperactivity disorder (ADHD) diagnosis,[1] which mirrors the presence of this condition among athletes.[2] Attention Deficit Hyperactivity Disorder (ADHD) is characterized by symptoms of inattention, hyperactivity, and impulsivity.[3] Researchers previously attributed ADHD to functional brain abnormalities of the pre-frontal cortex and basal ganglia.[4] More recently, a wide-ranging meta-analysis of functional magnetic resonance imaging (fMRI) studies, concluded that there were many variations in the functional networks of the brain that may contribute to ADHD symptoms.[5] Although there is still speculation about the areas of the brain primarily responsible for ADHD, stimulant treatments (e.g., methylphenidates) have been most successful in treating its symptoms. Methylphenidate medication causes an alteration in the dopaminergic processes in the brain, leading to a symptom resolution in individuals with ADHD.[6] Dopaminergic processes involve the release or inhibition of the neurotransmitter dopamine. Dopamine is present in the forebrain and basal ganglia, where it contributes to both motor and limbic processes (e.g., thinking processes).[6] Dopamine is also abundant in the frontal lobes, which primarily regulate both cognitive (e.g., working memory) and information processes.[6] Individuals with ADHD have imbalances within the dopaminergic pathways in the brain which may contribute to dysfunction with cognitive and memory processes.[6]

Concussion, like ADHD, presents with symptoms of both cognitive and memory complications, which may be due to ionic imbalances and an increase in neurotransmitters released in the brain (e.g., dopamine and glutamate).[7] Concussion is a growing public health concern due to the potential for deleterious and long-term cognitive effects.[8] Approximately 10 million patients visit the emergency room annually due to a concussion.[8] Of those, 3.8 million obtain a concussion from sport-related activities.[9] Typically, concussion symptoms resolve within 7-10 days, and high school and college age patients may fully return to play within 11-20 days.[11,12] However, some individuals may experience prolonged recover post-concussion. While some researchers consider concussion symptoms that last 30 days or more to be indicative of prolonged recovery,[13, 14] though this is not well defined. The presence of a learning disability (e.g., ADHD) and genetics (i.e., single nucleotide polymorphisms; SNPs) are risk factors for prolonged recovery time post-concussion.[10] Other risk factors for prolonged recovery from concussion include learning disabilities (ADHD, previous concussions, sex, and age.[10] Prolonged concussion recovery time and increased risk of a concussion are common for patients with ADHD.[10, 16-18] Assessing patients for intrinsic risk factors, such as ADHD, is important when considering concussion recovery. Another intrinsic risk factor that has not been fully parsed out is a patient's genome. Genotype in certain genetic markers may play a role in both concussion recovery and hereditary of learning disabilities such as ADHD.[10,19]

A single nucleotide polymorphism (SNP; i.e., a one nucleotide change within the genome) is denoted by rs1412005 within the promoter region of the Distant Subgroup of The Ras Family Member 2 (DIRAS2) gene is associated with ADHD diagnosis.[19, 20] The DIRAS2 regulates over 1,600 other genes, many of which have primary roles in neuronal proliferation and alteration.[21] A knockout study (i.e., a study where a gene is isolated and to determine the impact when a gene is no longer present) of DIRAS2 in murine hippocampal primary cells concluded that overexpression of DIRAS2 was a common occurrence in individuals with ADHD due to the presence of the risk allele (i.e., T).[21, 22] The investigation of SNPs linked to neuronal recovery has been a growing area of research in prolonged concussion recovery. Recently, a repeat polymorphism within the glutamate receptor ionotropic 2A (GRIN2A) gene was detected, and researchers found that carriers with 25 or more GT repeats were associated with a six-fold increased risk of concussion recovery lasting 60 or more days.[23] Additionally, the Apolipoprotein (APOE) E4 allele has been found to be associated with increased symptom reporting and higher recovery time following a sport-related concussion.[24]

There has been no research to determine an association between the alleles (i.e., G, T) within the DIRAS2, ADHD, and recovery time for sport-related concussion in the athletic population. If the rare allele (i.e., Thymine; T) polymorphism is found to be associated with an ADHD diagnosis, this may help medical professionals predict timing for recovery and safe return to play for athletes with ADHD. Therefore, the purpose of this study was to determine the association between the presence of the risk allele (i.e., T) in DIRAS2 and prolonged recovery (> 30 days) from sport-related concussion.

Method

Participants

This case-control study was designed to assess the presence of prolonged concussion recovery and the rare allele (i.e., T) within a cohort of individuals with ADHD and their non-ADHD counterparts. Case participants were defined as participants with self-reported ADHD. The control participants were defined as participants with no self-reported ADHD. Participants included 11 case individuals, matched by age and sex to 22 control individuals without ADHD (2 matched controls per case). Participants were recruited from 2 different sites (i.e. Temple University and Temple Hospital). All participants in this study had suffered a sports-related concussion. The average age of participants was 18 years (SD = 3) there were 30 males and 3 females and 70% of the sample population was Caucasian. Table 1 includes complete demographic information, as well as the sports played by participants. The average time to recovery from a sport-related concussion for the entire cohort of individuals was 17.27 days (SD= 11.23) The average concussion recovery time for the case participants was 21.5 days (SD= 13.96) while the control participants recovered within an average of 15.66 days (SD= 8.50). Further demographic information can be found in Table 1.

Table 1.
Demographic Information for the Cohort of Concussed Athletes

		Total	Case	Control
Factor	*n*	33	11	22
Sex			n (%)	
	Male		10 (91.00)	10 (91.00)
	Female		1 (9.00)	1 (9.00)
Race				
	Caucasian		8 (81.81)	13 (59.09)
	African American		0	5 (22.72)
	Hispanic/Latinx		0	1 (4.54)
	Native American		1 (9.09)	0
	Not Given		1 (9.09)	3 (13.63)
Sport				
	Football		5 (45.45)	8 (36.36)
	Rugby		1 (9.09)	3 (13.63)
	Baseball		1 (9.09)	1 (4.54)
	Basketball		1 (9.09)	1 (4.54)
	Ice Hockey		1 (9.09)	1 (4.54)
	Soccer		1 (9.09)	5 (22.76)
	Fencing		0	1 (4.54)
	Wrestling		1 (9.09)	2 (9.09)
			Mean ± SD	
Age (yr)		18 ± 3	18 ±3	18 ± 3
MR (d)		19 ± 12	22 ± 14	16 ± 9
PDC		2 ± 1	1 ± 2	3 ± 2

Note. Mean recovery (MR) is measured in days (d) and dictates mean recovery from sport-related concussion and PDC dictates previous diagnosed concussions.

Measures

Participants completed a standardized initial concussion evaluation, where the following parameters were assessed: injury characteristics including the date and time of injury, mechanism of injury (e.g., direct impact, rapid acceleration, and deceleration), acute signs and symptoms (e.g., loss of consciousness, dizziness), patient history including self-reported prior concussion history, migraine, ADHD disclosure, and psychiatric history (e.g., depression). The initial evaluation was followed by an objective screening, which included vestibular ocular assessments, the Balance Error Scoring System (BESS) test, and an online Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). Previously recorded baseline scores were used to determine an athlete's readiness to return to play. Using these data, for each participant we assessed number of days to full recovery and status of ADHD diagnosis.

DNA Extraction and Genotyping

This SNP rs1412005 was chosen based on its primary expression within the brain, association with ADHD, and the minor allele frequency of greater than or equal to 0.40. The SNP rs1412005 is located in the promoter region of *DIRAS2*, which is located on chromosome 9 in the promoter region. The promotor region of *DIRAS2* has possible risk of the target SNP having some phenotypic response compared to choosing a SNP in the intron region of a gene.[25] The promoter region of this gene dictates the amount of small Ras GTPase protein that is produced. Small Ras GTPase proteins play an important role in cell development, discrimination, and survival.[25]

Salivary samples for genotyping and DNA isolation were collected using Oragene DNA Self Collection Kits (DNA Genotek, Ottawa, ON, Canada). DNA was extracted according to the manufacturer's instructions. Purified DNA was quantified using a Quant-it PicoGreen DNA assay kit (Invitrogen, Carlsbad, CA). The DNA region surrounding position in the promoter of DIRAS2 was amplified (taqman assay kit number C___3069317_10). The cycling conditions were incubation for 30 min at 48^{o}C, 10 min at 95^{o} C, followed by 40 cycles of 15 sec at 95^{o}C and 1 min at 60^{o}C. Real Time-Polymerase Chain Reaction was terminated after 35 cycles and all genotyping measures were read at 30 cycles to ensure the most accurate allelic discrimination. To validate the analytical method for SNP genotyping, a pedigree analysis of both the G/T alleles in a three-generation family was performed. The pedigree chart analysis confirmed that the protocol in this work was accurate in detecting both the homo- and heterozygous allelic variants and that the corresponding alleles were inherited according to Mendel's laws. Additionally, gel electrophoresis was used to quantify and check the purity of the reaction process using 1.4% agarose. After electrophoresis at 100mV for 1 hr, the gels were inspected under UV light, and the images were recorded.

Data were analyzed using descriptive and inferential statistics. A one-way Analysis of variance (ANOVA) was used to identify the association between number of days to full concussion recovery, ADHD diagnosis, and allele frequency. An odds ratio was utilized to predict the relative odds between prolonged recovery for individuals with ADHD and their non-ADHD counterparts. Three 2 (allele) x 2 (group) chi-square tests were used to assess the association between the allele frequency of *DIRAS2* SNP, ADHD diagnosis status, and prolonged recovery. SPSS version 26.0 (SPSS IBM Inc., Armonk, NY) was used for all analyses, and the alpha level was set to $p \leq 0.05$.

Results

Concussion and ADHD

An odds ratio test revealed that individuals in the study with self-reported ADHD were five times more likely to have prolonged recovery than their non-ADHD counterparts (CI= 95%) A chi-square test revealed a significant difference between presence of ADHD and concussion recovery (p= 0.044). Forty-five percent of individuals with ADHD had prolonged recovery from concussion, while 54% of the individuals with ADHD had normal concussion recovery.

Eighty-six percent of the individuals with no presence of ADHD had normal concussion recovery time (i.e., less than 30 days) and only 13% of those individuals had prolonged concussion recovery. This suggests that patients with ADHD have a significantly longer recovery time post-concussion, compared to patients without ADHD.

ADHD and DIRAS2 Genotype

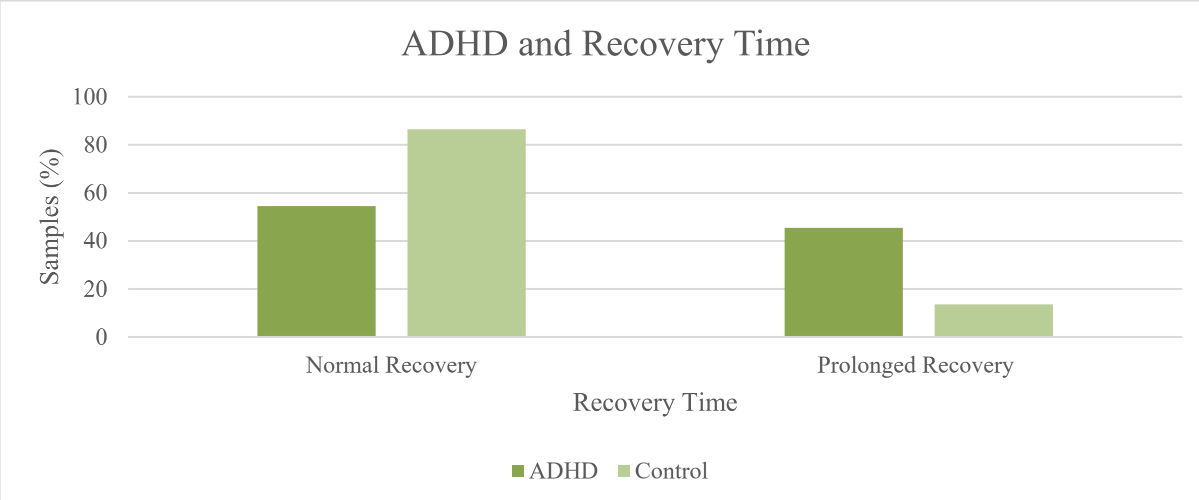
There was no significant difference between the presence of ADHD and the rare allele genotype (i.e., GT; p=0.213), see results in Table 2.

Table 2.
ADHD Diagnosis, Genotype, and Prolonged Recovery Relationship

Factor	Outcome	Case	Control
Total Sample		11	22
Allele	%G	27.30	50.00
	%T	72.70	50.00
Recovery	%Normal	54.40	86.40
	%Prolonged	45.50	13.60*

*Note. Presence of allele present in each group (case and control) is shown. * dictates p=0.044* and Figure 1. Seventy-two percent of individuals with the GT genotype had an ADHD diagnosis.

Figure 1.
Relationship Between Presence of ADHD and Sport-Related Concussion Recovery Time.



Note. ADHD = Attention Deficit Hyperactivity Disorder, Normal Recovery < 30 days, Prolonged Recovery > 30 days

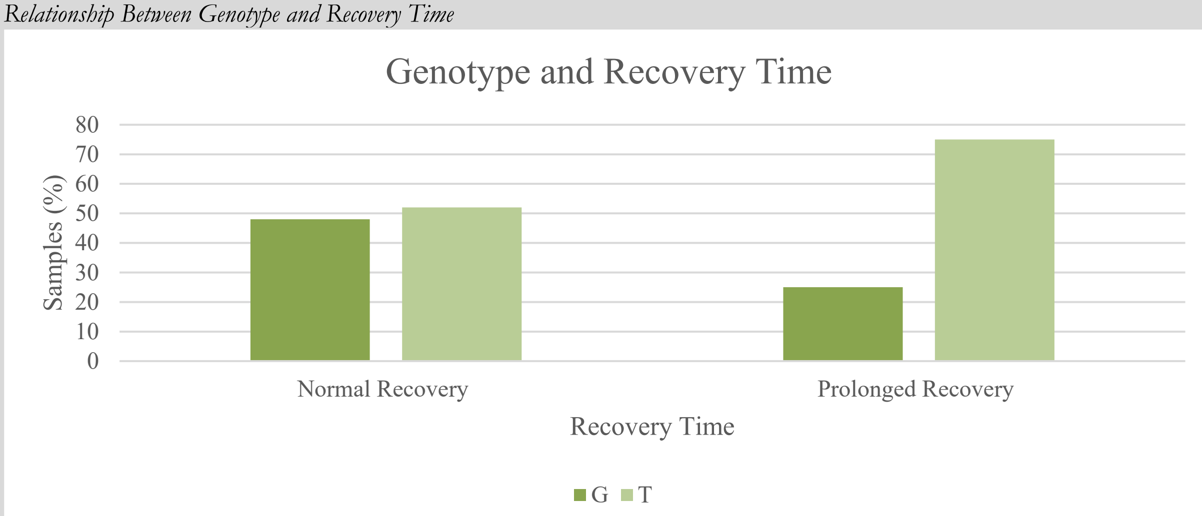
Concussion Recovery and DIRAS2 Genotype

A chi-square test between genotype and concussion recovery revealed no significant difference for genotype and prolonged concussion recovery (p=.0.252). Additional information about the relationship between concussion recovery and genotype can be seen in Table 2.

ADHD, Genotype, and Concussion Recovery

There was no significant association between days to full concussion recovery, the presence of ADHD, and genotype (p= *0.143*). The relationship between self-reported ADHD status, genotype, and concussion recovery can be seen in Figure 2.

Figure 2.
Relationship Between Genotype and Recovery Time



Note. GG= Common genotype, GT= Rare genotype

Discussion

A variety of risk factors may contribute to the probability of prolonged recovery following sport-related concussion. This study sought to investigate the presence of the rare allele (i.e., T) in the promoter SNP within *DIRAS2*, ADHD, and their association with concussion recovery lasting 30 or more days. Individuals with ADHD were found to be five times more likely to suffer from a prolonged concussion recovery (CI=95%) compared to their non-ADHD counterparts. The American Society for Sports Medicine position statement on concussion in sport described ADHD as a risk factor for abnormal concussion outcomes due to its association with cognitive dysfunction.[9] A study comparing recovery time for individuals with ADHD and their non-ADHD counterparts found a three-day difference between the patients, solely based on their ADHD status.[17] Miller and colleagues also found ADHD to be a predicator for prolonged concussion recovery of greater than 28 days.[26] This may be due to an exacerbation of athletes' ADHD symptoms because of the common symptomology between concussions and ADHD.[7]

Attention Deficit Hyperactivity Disorder status was not significantly predictive of a higher likelihood of the presence of the rare allele, T, within this cohort of 33 athletes (72.7% in cases vs. 50% in controls). The *DIRAS2* rare allele, T has been previously associated with an ADHD diagnosis.[20] The minor risk allele led to the increased expression of DIRAS2.[22] DIRAS2 RNA expression was found to be heavily expressed in the hippocampus, cerebral cortex, and the cerebellum, all regions of the brain responsible for cognitive and memory function.[22] Use of the western blot technique found the highest expression levels of DIRAS2 in the frontal cortex, hippocampus, amygdala, and striatum of the brain[22] which are areas of the brain involved in working memory, error detection, executive function.[19] Specifically, the neurotransmitters dopamine and glutamine within the striatum were found to have an association with altered cognitive function.[7]

Seventy-five percent of individuals that disclosed a diagnosis of ADHD and were found to be carrying the T allele had prolonged recovery, while only 25% of the controls experienced this outcome. Additionally, researchers found that 100% of the individuals with the G allele recovered in 30 days or fewer (Figure 2). The rare allele T has been found to be associated with the over-expression of DIRAS2, which plays a role in the regulation of 1,612 genes.[21] Of the genes regulated by *DIRAS2,* many were found to play a role in processes involving glutamate.[22] Glutamate is a key neurotransmitter in the neurometabolic cascade that occurs following a concussion.[27] The Neurometabolic Cascade theory following neuronal strain suggests that the release of glutamate, as an excitatory neurotransmitter, promotes accumulation and influx of intracellular sodium and calcium. This leads to cell and mitochondrial damage within the neurons.[27] Due to the increased need for homeostasis propagated by the mitochondria, there is a subsequent energy crisis that occurs. The energy crisis has been shown to propagate poorer cognitive function in animal studies.[27] Glutamate has also been found to be associated with alterations with the neurotransmitter dopamine. A study found that the administration of glutamate into the ventral striatum reduces the uptake of dopamine[7]. Dopamine has been an important neurotransmitter involved in the symptomology of ADHD. Dopamine plays an important role in motor control, motivation, cognitive functions, and other functions of the body.[28] Due to the relationship between glutamate and dopamine, concussion impact may be more debilitating for individuals with an ADHD diagnosis, which may lead to prolonged concussion recovery.

Limitations and Future Research

Although there was an association between prolonged concussion recovery and the presence of ADHD, the demographic information may have been affected by recall bias. For example, the presence of ADHD was self-reported at the beginning of the study. Some participants may have chosen not to self-report their ADHD diagnosis status, or their diagnosis could have changed throughout the duration of the study. Further research with a larger and more diverse population is necessary to determine the overall significance of this SNP. To determine a widespread genome significance, it would be necessary to conduct a genome-wide analysis study examining the relationship between *DIRAS2* and genes that it affects as a proliferation switch. Lastly, the control group reported more previous concussions, a contributing risk factor for prolonged concussion recovery, than our case group, which may have affected our findings.[17,18]

Clinical Implications

Individuals with ADHD have a higher likelihood of prolonged concussion recovery, which may be associated with the presence of the rare allele (i.e., T) within *DIRAS2*. The DIRAS2 protein is highly expressed in brain regions that play a role in genes that regulate dopamine and glutamine processes, which have been found to cause dysfunctions in both cognitive function and memory. Clinicians should use this knowledge to counsel individuals with ADHD on their timeline to return to play from sport-related concussion.

About the Authors

Taziah Kenney is a visiting assistant professor within the College of Life Sciences at Thomas Jefferson University. She earned her M.S in Kinesiology at Temple University. Currently, she is pursuing a Doctor of Education with a line of research focused on student success and retention in special populations.

Jane McDevitt is an assistant of instruction in the Department of Health and Rehabilitation Sciences at Temple University. She earned her PhD in Kinesiology at Temple University. Currently, she is the director of the Sport Concussion Lab, where her primary line of research is in the risks of prolonged recovery following a concussion.

Conflicts of Interest

The authors declare no conflicts of interest.

Statement of Contributions

T.K. and J.M. contributed to the design and implementation of the research, the analysis of the results, and the writing and editing of the manuscript.

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Social Media Use and Physical Activity Participation in College Students: An Exploratory Analysis

AMANDA L. FOLK, MS[1]; SARA J. KOVACS, PHD[2]
[1]School of Kinesiology, College of Education and Health Development, University of Minnesota
[2]Department of Kinesiology, College of Public Health, Temple University

Correspondence: folk0039@umn.edu (Amanda L. Folk)

***Background**: Social media has become a part of a college student's environment, highlighting the importance of investigating the role that social media may play in physical activity (PA) participation and other health behaviors. **Purpose**: To describe social media use and PA participation in a sample of college students and explore relationships between social media and PA, including health and fitness social media. **Methods**: College students (age 18-29 years) enrolled at a four-year university during the 2018-19 academic year completed an online questionnaire regarding self-reported social media use and PA participation. Independent sample t-tests were used to compare PA outcomes between those that follow health and fitness accounts and those who do not. A multiple linear regression model was used to examine associations between social media use and PA. **Results**: Two hundred and ninety-two students completed the questionnaire (63.72% female, 63.61% white). There was no difference in PA participation between those that do and do not follow health and fitness social media in moderate (p=0.40) or vigorous intensity PA (p=0.06) when controlling for confounding variables. Spending 1-2 hours/day (p=0.02) or 3-4 hours/day (p=0.01) on social media compared to <1 hour/day and accessing social media in the evening (p=0.04) are associated with lower moderate PA. **Conclusions**: Following health and fitness social media may not have the intended impact on college student PA. Further research needs to be done to assess the most effective and impactful strategies for content delivery via social media to increase PA behavior.*

***Keywords**: college student physical activity, social media, exercise, health promotion*

Introduction

Physical activity (PA) is associated with numerous positive health outcomes which are realized regardless of age, sex, and body weight.[1] Health benefits of regular PA include reduction in risk for all-cause mortality, cardiovascular morbidity and mortality, type 2 diabetes, and certain cancers.[1,2] Some benefits from PA are realized immediately, including acute reductions in anxiety symptoms and blood pressure.[1] The American College Health Association reported that 31.4% of college students surveyed in Fall 2020 reported anxiety as affecting their individual academic performance, which was second only to stress.[3] Since PA has the potential to reduce anxiety and improve health, as well as reduce the risk for many common chronic conditions, encouraging college students to be physically active is essential.

The minimum aerobic PA recommendation, per the 2018 Physical Activity

Guidelines, is 150 minutes of moderate intensity PA, 75 minutes of vigorous intensity PA, or a combination of the two per week to accrue these health benefits.[1] Despite the numerous benefits college students can gain from being physically active, studies indicate that PA participation in college students is often below recommended guidelines and that PA participation further tends to decrease each semester of college.[4–6] Recent data suggest over one third of college students are physically inactive, as per the aerobic guidelines.[3,7] There may be an association between meeting PA guidelines and better mental health outcomes,[7] and thus PA promotion has been identified as a priority for some institutions.[8] College is an opportunity for young adults to make independent decisions about their behaviors. It is a crucial time for promoting health and sustainable PA behaviors that may continue into adulthood.[9] Identifying determinants of PA, as well as effective and feasible strategies for PA promotion among college students, may help these young adults meet activity guidelines and benefit from the associated health effects.

While college students in general seem to have low PA participation, it is clear that they are spending their time regularly engaging with social media. Social media serves as a platform for communication activities and examples include online social networks such as Twitter, Facebook, YouTube, and Instagram.[10] It is estimated that 90% of American adults ages 18-29 use social media,[11] up from 12% in 2005.[12] Social media has become a part of a college student's environment, indicated by its rapid growth, highlighting the importance of investigating the role that social media may play in PA participation and other health behaviors.

There is currently a gap in the literature regarding the relationship between college social media use and PA participation. One study reported no relationship between social media use and PA engagement in a sample of 512 college students. However, it should be noted that the study only recruited students that were enrolled in for-credit PA and nutrition classes so may not be representative of the general college student population.[13] Screen time, defined as time spent using computers, watching television or DVDs, and/or playing video games, has been shown to be related to American college students being sufficiently active or not.[14,15] Screen time may include social media use, but does not capture the specific effect of social media and thus it is essential to separate the two to gain a clearer picture as to how social media affects PA. For example, a focus group of 17 male and 29 female college students in Belgium highlighted internet communication and technology as a behavior leading to sedentary behavior whereas media and advertising as a factor influencing PA behavior.[16] Since both internet communication and media and advertising are central on social media, further exploration is needed into these relationships. Relationships are seen between social media and health behaviors such as alcohol consumption, indicating that what individuals see on social media may influence other health behaviors, like PA.[10,17] However, the relationship between following health and fitness social media accounts and PA behavior is unexplored.

One objective of the present study was to describe social media use characteristics and PA behaviors in a representative sample of college students and further examine the relationships between those variables. The researchers also aimed to see if average minutes per week of PA differed between those who reported following health and fitness social media accounts or not. If health and fitness social media were effective in its current form as promoting PA behavior, there will be a difference in average PA levels between participants who follow health and fitness social media accounts and those that do not. Finally, the researchers aimed to identify if social media use variables (i.e., hours spent on social media, social media use patterns) were associated with moderate or vigorous intensity PA while accounting for demographic variables. The researchers hypothesized that time spent on social media and time of day spent on social media would be associated with PA behavior.

Materials and Methods

This study was conducted with students enrolled at a four-year university in the United States during the Fall and Spring semesters of the 2018-2019 academic year. College students completed a one-time questionnaire regarding social media use and PA participation. The questionnaire was supported through Qualtrics software, an online survey platform.

Survey Measures

Social Media Use: The questionnaire included questions regarding a college student's social media use, both in terms of content and timing. Participants were asked if they used social media daily and, if yes, which social media platforms they interacted with daily. Participants were also asked how many hours per day (on average) do they use social media, what time of day they use social media the most, and when do they access social media (e.g., when they wake up, during mealtimes). Finally, participants were queried on if they specifically follow health and fitness social media accounts, which was intentionally inclusive of whatever the participants deemed as "health and fitness."

Self-Report Physical Activity. Physical activity was measured through self-report using the International Physical Activity Questionnaire - Short Form, which has been validated in a college student population.[18] This questionnaire asks participants to think about the vigorous- and moderate- intensity PA they have done in the past seven days and identify how many of those days they did that type of activity, as well as how much time they usually spent doing that type of PA on one of those days. The number of days is multiplied by this duration to calculate average minutes per week of a given intensity of PA.[19]

Participants

Students were recruited through an email sent to all students enrolled in classes in the College of Public Health at a four-year university, which includes Kinesiology, Communication Sciences and Disorders, Epidemiology and Biostatistics, Health and Rehabilitation Sciences, Health Services Administration and Policy, Nursing, School of Social Work, and Social and Behavioral Sciences Departments. While this was a convenience sample, students outside of these departments were able to take this survey if shared with them through peers. Students were eligible to participate if they were between 18 and 29 years old and a student currently registered for classes during the semesters of data collection. Informed consent was obtained from participants on the first page of the online questionnaire.

At the end of data collection, 394 survey responses were recorded. Responses from students who did not meet the age inclusion criteria or who were not currently registered for classes were excluded. Additionally, incomplete responses were excluded. The final number of participants included in this study was 292.

Statistical Analyses

Statistical analyses were conducted using SAS version 9.4. In order to describe the sample, means and standard deviations or frequencies were calculated for each of the demographic, social media use, and PA variables. Independent sample t-tests were used to compare mean PA outcomes between those that follow health and fitness accounts and those who do not to see if there was a difference in average PA between groups. Finally, a multiple linear regression model was used to examine potential associations between social media use and PA. The linear regression model included hours of social media use per day, the time social media was most accessed, and whether or not health and fitness accounts are part of the social media consumption. Additionally, sex and residence were entered into the model to be controlled for, as both have been shown to affect PA in college-aged individuals[6]. Statistical significance was set at $p \leq 0.05$. Temple University's Institutional Review Board deemed the study met exemption status due to minimal risk involvement and anonymous survey methodology.

Results

Demographics, social media use, and self-reported PA behavior of the entire sample can be found in Table 1. The majority of the sample was compromised of females (69.7%) and White individuals (63.6%). A majority of the sample reported using social media daily (96.6%), with most of the sample reporting either 1-2 hours or 3-4 hours of social media use per day (41.4% and 43.1%, respectively). Instagram was the most popular social media platform used by the sample, followed by Snapchat. Over half of the sample (55.9%) reported the most popular hours of use between 8pm and 12am. Those that reported following health and fitness accounts (n=228; 78.6%) reported an average of 189.4 ± 178.0 min/week of moderate PA and 268.9 ± 197.7 min/week of vigorous PA. In contrast, those that reported not following health and fitness accounts reported an average of 164.2 ± 158.6 min/week and 270.9 ± 249.6 min/week, respectively. There were no statistically significant differences for either moderate (p=0.40) or vigorous (p=0.06) intensities of PA between those who report following health and fitness accounts and those who do not.

Table 1.
Survey Results: Demographics, Social Media Use, & Physical Activity

Demographics	**Mean ± SD or n (%)**
Sex*	
Female	205 (69.73)
Male	89 (30.27)
Race/Ethnicity	
White	187 (63.61)
African American or Black	39 (13.27)
Hispanic or Latinx	27 (9.18)
Native American	1 (0.34)
Asian	39 (13.27)
Two or More Races	11 (3.74)
Other	17 (5.78)
Residence	
University-Owned Housing	69 (23.47)
Home of parents/relative	64 (21.77)
Own home/apartment	154 (52.38)
With other family members	1 (0.34)
Other	6 (2.04)
Social Media Use	
Use social media daily	284 (96.60)
Use Facebook	154 (52.38)
Use Twitter	134 (45.58)
Use Instagram	259 (88.10)
Use YouTube	150 (51.19)
Use Snapchat	240 (81.63)
Use other	22 (7.48)
What time of day do you use social media the most?	
Morning (6am-10am)	13 (4.48)
Mid-day (11am-2pm)	15 (5.17)
Afternoon (3pm-7pm)	100 (34.48)
Evening (8pm-12am)	162 (55.86)
How many hours per day do you use social media?	
<1 hour	22 (7.59)
1-2 hours	120 (41.38)
3-4 hours	125 (43.10)
5+ hours	23 (7.93)
Follow health/fitness accounts on social media	228 (78.62)
Physical Activity Behavior	
Moderate (min/week)	184.45 ± 174.23
Vigorous (min/week)	269.20 ± 206.32

*No participants reported a sex other than male or female, so that option is not reported in this table

Results from multiple linear regression models can be found in Table 2 for moderate intensity PA and Table 3 for vigorous intensity PA. Those that follow health and fitness accounts participate in moderate intensity PA. average 42.90 more min/week than those who do not when controlling for sex, residence, how often an individual uses social media, and what time of day social media is used. This effect is not statistically significant (p=0.21) but may be interesting to note. Also of note is the effect of amount of social media use on moderate intensity PA.

When compared to those that use social media less than one hour per day, those who used social media between 1-2 hours report on average 104.96 fewer minutes of moderate PA per week (p=0.02) and those who used social media between 3-4 hours per day report on average 116.65 fewer minutes of moderate PA per week (p=0.01). Time of day that social media is accessed most may also be associated with moderate PA. Those who accessed social media most in the evening reported participating in, on average, 126.81 fewer minutes of moderate intensity PA per week compared to those who access social media most in the morning (p=0.04).

While not statistically significant (p=0.06), those who accessed social media most in the afternoon reported, on average 116.48 minutes per week fewer than those who most engaged with social media in the morning. The results regarding vigorous PA, however, are different. Those that followed health and fitness accounts participated in vigorous intensity PA only an average of 0.02 more min/week than those who do not when controlling for sex, residence, how often an individual uses social media, and what time of day social media is used.

Table 2.
Moderate Physical Activity Regression Model

Parameter	β Estimate	SE	t-value	p-value
BMI	-3.31	2.98	-1.11	0.27
Sex				
Females	-46.74	30.93	-1.73	0.08
Males[1]	-	-	-	-
Residence				
Home of parents/relatives	-49.28	37.86	-1.30	0.19
Own home/apartment	-21.57	31.22	-0.69	0.49
With other family members	-155.77	182.80	-0.85	0.40
Other	-31.80	91.73	-0.35	0.73
University-Owned Housing[1]	-	-	-	-
Social Media Use: hours/day				
1-2 Hours	-108.02	44.08	-2.45	0.02*
3-4 Hours	-120.91	45.61	-2.65	0.01**
5+ Hours	-7.64	65.00	-0.12	0.91
<1 Hour[1]	-	-	-	-
Social Media Use: time of day				
Mid-Day	-86.64	86.34	-1.00	0.32
Afternoon	-108.53	62.53	-1.74	0.08
Evening	-122.56	60.52	-2.03	0.04*
Morning[1]	-	-	-	-
Follows Health & Fitness Account				
Yes	42.90	30.93	1.39	0.17
No[1]	-	-	-	-

*p<0.05 **p<0.01 [1]Indicates reference group for this variable.

Table 3.
Vigorous Physical Activity Regression Model

Parameter	β Estimate	SE	t-value	p-value
BMI	-0.30	3.47	-0.09	0.93
Sex				
Females	-91.34	31.28	-2.92	0.004**
Males[1]	-	-	-	-
Residence				
Home of parents/relatives	-76.58	45.54	-1.68	0.09
Own home/apartment	-64.58	34.20	-1.89	0.06
With other family members	-277.76	219.52	-1.27	0.21
Other	-102.78	109.08	-0.94	0.35
University-Owned Housing[1]	-	-	-	-
Social Media Use: hours/day				
1-2 Hours	2.98	51.09	0.06	0.95
3-4 Hours	-29.56	52.65	-0.56	0.58
5+ Hours	50.33	73.24	0.69	0.49
<1 Hour[1]	-	-	-	-
Social Media Use: time of day				
Mid-Day	-39.95	97.47	-0.41	0.68
Afternoon	48.90	75.22	0.65	0.52
Evening	32.51	72.93	0.45	0.66
Morning[1]	-	-	-	-
Follows Health & Fitness Account				
Yes	0.17	38.90	0.00	1.00
No[1]	-	-	-	-

$^{*}p<0.05$ $^{**}p<0.01$ [1]Indicates reference group for this variable.

This effect is not statistically significant (p=1.00). Interestingly, there seems to be no statistically significant effect of number of hours per day social media is used on vigorous intensity PA, nor an association with time of day that social media is most used

Discussion

This study aimed to explore social media use characteristics and PA in a representative sample of college students. Most participants in the sample use social media daily (96.6%), which is not unlike national samples.[11] Further, almost 79% of the sample follows some sort of health and fitness channel on social media and it is clear in the literature that young people are getting health information from social media.[20] Data from the present study do not indicate students who are receiving health and fitness content are participating more in favorable health behavior. Indeed, there is no statistically significant effect of following these social media channels on either moderate or vigorous PA.

Despite this lack of significant effect, literature suggests social media seems to be a potential intervention strategy for changing health behaviors, including increasing PA.[21–23] However, it should be noted that almost all of the currently existing intervention studies used Facebook as the social media platform in the interventions.[24] Out of three interventions specifically in college students with the goal of increasing PA, two used Facebook and one used a platform unique to the study.[25–27] Facebook may be useful as a tool to increase social support and encourage PA behaviors.[26] If the goal is to reach all college students, however, data from the present study indicate that Facebook may not be reaching the general college student, as only 52.4% of the sample reported using Facebook each day. Facebook had the lowest engagement of all social media platforms included in this questionnaire; this tends to differ from studies looking at social media use across adulthood.[28]

There is some evidence that people who are not regularly physically active can be influenced to be active through content such as workout posts.[28] However, the present sample suggests health and fitness channels as they exist now do not seem to be associated with more PA in the sample of college aged participants. Perhaps the content is not effectively promoting PA behavior or the students are not actually seeing or engaging with that content, due to social media algorithms that are unknown to the public.[29] Further qualitative studies focusing on accurately assessing what health and fitness-related content college aged students are viewing and interacting with on their social media feeds is warranted. This type of analysis will provide much needed insight to researchers who intend to use social media as an intervention tool for behavior change, specifically an increase in PA behavior.

This study did have strengths, one of which is reflected in the sample itself. This is the first survey to the research team's knowledge that surveyed a sample that was not comprised of those students only enrolled in PA participation classes.[13] Since enrollment in these types of classes may already influence a participant's PA behavior, the present sample may be more generalizable to a student body. Additionally, this is the first study to the research team's knowledge that contained survey questions specifically related to health and fitness accounts on social media. Descriptive data of this kind is essential when examining social media as a potential intervention strategy for PA. An additional strength is related to the demographics of the students surveyed. The research team was able to recruit a sample that is representative of the student body of the university. Temple University is an urban campus, so the results may not be generalizable to all college campuses.

Many of the weaknesses of this study are a result of the survey study design. The data presented are cross-sectional in nature, therefore, no causal relationships were able to be explored. Additionally, the sample size is small relative to a typical college campus and was predominantly female. While a smaller sample size may be acceptable for the first steps of establishing these relationships, further surveys should be conducted in a larger sample. Finally, there are limits to the generalizability of this study. While participants were not limited to belonging to the University's College of Public Health, classes in the College were used as a starting point for recruitment. This convenience sample may lead to a higher proportion of participants who are interested in health and fitness.

The survey questions also may have led to some challenges that provide opportunities for further research studies to capitalize on. The PA survey questions were from the International Physical Activity Questionnaire - Short Form. These have been validated in a college-aged sample,[18] but did not seem to result in an overall average realistic response in the sample. For example, the average amount of vigorous PA in the sample was 269.2 ± 206.3 minutes per week. There is a known tendency for individuals to over report PA,[30] particularly college students using IPAQ,[31] and some of the relationships analyzed as part of this study may be affected as a result. The variability in PA data indicates a need for objectively collected PA data in a college aged sample as a next step. While there are no validated survey questions regarding social media for this population to the researcher's knowledge, social media can be challenging to research because of the constantly changing nature of platform popularity. For example, this survey did not include TikTok and only one participant reported using it regularly under the response of "Other." While the options presented were reasonable for the time of the initial survey, TikTok has become increasingly popular and would need to be included in further surveys.

Additional research may be of interest to universities in different locations. As previously mentioned, this survey was conducted on an urban campus. Perhaps this is not generalizable to, for example, a rural college town. Next steps could involve looking at different university locations with similar surveys to see if results differ between institutions. While this survey is the first of its kind to question participants on health and fitness accounts specifically, more research needs to be done regarding what specifically these students are seeing. This will be crucial for social media intervention design and implementation to ultimately increase PA in college aged students. Finally, many college students are experiencing a strain on their mental health in terms of being overwhelmed, stressed, exhausted, and/or lonely.[3] PA is often cited for its brain health benefits (reduced anxiety and depression risk; improved quality of life), so increasing PA in college students is of the utmost importance[1] It remains unclear if social media is responsible for mental health problems among young adults, though one study suggests how social media is used may be more insightful than general use patterns.[32] Thus, future studies intervening upon PA using social media, or further exploring relationships between the two, may want to include mental health as a secondary outcome variable to ensure the intervention is protecting and not further affecting their mental health.

In conclusion, this study provides descriptive statistics for an urban university regarding social media use and PA behavior. There were no statistically significant differences in self-reported PA behavior between those that follow health and fitness social media accounts and those that do not. However, the difference in moderate intensity PA may be practically significant; those that follow health and fitness accounts on average reported engaging in 42.9 min/week more compared to those that do not follow health and fitness accounts. Time spent on social media per day seems to be associated with moderate PA, as well as time of day social media is most accessed. Results from this study could be used to inform further social-media related research in college students, as well as inform professionals who use social media as a tool to encourage PA behaviors in college students.

Conflicts of Interest

The authors have no conflicts of interest.

ORCID IDs

Amanda L. Folk - 0000-0001-8424-9265
Sara J. Kovacs - 0000-0002-5000-7900

Statement of Contributions

Conceptualization, A.L.F., S.J.K.; methodology, A.L.F., S.J.K.; formal analysis, A.L.F.; writing—original draft preparation, A.L.F.; writing—review and editing, A.L.F., S.J.K. All authors have read and agreed to the published version of the manuscript.

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The Effects of a Single Bout of Soccer Heading on Single and Dual-Task Gait in Collegiate Recreationally Active Individuals

KARLEE BURNS, MS ATC[1]; MADISON LOHR, MS, ATC[1], JANE MCDEVITT, PHD, ATC, CSCS[2]
[1]Department of Kinesiology, College of Public Health, Temple University
[2]Department of Health and Rehabilitation Sciences, College of Public Health, Temple University

Correspondence: jane.mcdevitt@temple.edu (Jane McDevitt).

Introduction: *The understanding of subconcussive impacts is limited, with few assessments to determine effects in a recreationally active population due to existing tests being static and unidimensional.* **Methods**: *This study investigated the effects of 10 soccer headers on pre and post-test measurements of patient reported outcome measures and single and dual-task tandem gait of 12 recreationally active college-aged participants.* **Results**: *No changes due to the heading session were observed; however, there was a detectable learning effect with participants walking faster and committing more gait errors but less cognitive errors.* **Conclusion**: *A bout of soccer heading may not pose an immediate risk to dynamic postural control and cognitive function.*

Keywords: *Concussion, Subconcussion, Assessment, Cognition*

Introduction

Repetitive head impacts (RHI) are mild impacts that do not result in concussion symptoms or diagnosis.[1] Research investigating the outcomes of RHI in athletes has identified negative cognitive and neuropathological effects, though identifying the subtle functional impairments that transpire are difficult, resulting in conflicting reports.[2-6] Given the frequency of RHI in sport, the public health implications of these effects may be significant.

RHI are common in soccer, where excess heading of the soccer ball,[7] may result in subclinical problems, which were not explained with a history of a concussion diagnosis.[8] Further, soccer players that head the ball more frequently reported higher symptom scores.[2] Having dynamic, functional, and sensitive measures to assess the effects of RHI would be beneficial.[9]

There have been several investigations using different concussion assessments to identify the effects resulting from RHIs following soccer headings. Cognitive exams revealed decreased voluntary control and slower reaction times[4,6] and after 10 soccer headings, the effects of RHI were observed in the oculomotor system with near point of convergence measures changing.[10] Negative cognitive and oculomotor changes are indicative of poor health outcomes. However, acute and cumulative effects of soccer heading using balance assessments have conflicting findings (e.g., are postural control deficits present).[5,6] Many of the balance assessments employed were static measures and may not engage the functionality that is necessary for an athletic population.[9]

The single and dual-task tandem gait assessments are used to evaluate dynamic balance and have an 80% sensitivity in identifying effects of concussion two weeks post injury.[12,13] In single-task tandem gait, multiple systems are required to coordinate and execute this movement, which is more demonstrative of the skills required of athletes; therefore, this type of assessment is more applicable than a static balance measure.[14] Dual-task assessments pair dynamic postural control with a cognitive task to further challenge the individual.[14]

With the various clinician-based outcomes (e.g., balance, cognitive testing) currently in use, implementing validated patient reported outcome measures (PROM) like the Disablement in Physically Active Scale (DPAS) and Post-Concussion Symptom Scale (PCSS) could be beneficial in determining if the athlete themselves identifies any changes. Though specific questionnaires for concussion and subconcussion have not yet been developed, the DPAS and PCSS can identify functional limitations, impairments, quality of life changes in physically active individuals.[15-17] If signs are symptoms (e.g., PCSS) are reported after a head impact, clinicians should further evaluate for concussion.

Changes in self-reported symptoms after an acute soccer heading model have been identified; however, functional details and PROMs were not reported.[16] Further, dynamic changes have been found following concussion[12] or after an acute bout of soccer heading,[11] but needed expensive laboratory equipment and lacked details regarding how the athlete believes they are being affected by the RHIs. Therefore, the purpose of this study was to investigate the effects of RHIs from an acute bout of soccer headings on single and dual-task tandem gait tasks and PROMs in recreationally active college-aged individuals.

Methods

Participants

Twelve collegiate students volunteered to participate in the study. Individuals were eligible to participate if they self-reported they were healthy, aged 18 years or older, and had five or more years of lifetime soccer heading experience. Individuals were excluded if they had self-reported abnormal gait deficits, concussion or lower extremity injury in the previous 6 months, or vestibulo-ocular dysfunctions (e.g., inner ear infection, vertigo). This study was approved by Temple University's Institutional Review Board and participants signed an approved consent form prior to data collection.

Instrumentation

Patient Reported Outcome Measures

The Post-Concussion Symptom Scale (PCSS) consists of 22 symptoms rated on a scale of 0 (i.e., not experiencing) to 6 (i.e., most severe). Total severity score was determined by adding each of the 22 ratings.[17] The DPAS assesses the physical ability of patients (e.g., changing directions, overall fitness). The scale consists of 16 questions rated from 0 (i.e., no problem) to 4 (i.e., the problem severely affects the patient).[18]

Accelerometer

A triaxial accelerometer was affixed with a headband (G Force Trackers, Richmond Hill, Ontario) and placed on the participant's occiput to measure head kinematics (i.e., linear and rotational acceleration) during the soccer header.[19]

Tasks

Single-Task Tandem Gait

The participants were instructed to walk along a 3m strip of tape in a heel-to-toe fashion with hands on hips to the end of the tape, turn 180°, and return in the same heel-to-toe fashion completely past the original starting point of the tape. Each participant was informed on what an error was (i.e., heel does not meet toe, steps off tape, takes hands off hips). To streamline data collection and for ease of clinical application all participants completed one practice trial and two measured trials for the pre-test and three trials post-test.[20,21] In addition to trial time and tandem gait errors, additional gait outcome measurements (e.g., cadence) were included in this study. These outcomes were chosen for their clinical application and prior inclusion in gait and concussion literature.[22] All trials were video recorded for post-processing.[6]

Dual Task Tandem Gait

This gait assessment was performed in the same manner as the single-task gait assessment with the inclusion of a cognitive task. For the cognitive task, a 5-letter word, based on 5th grade comprehension, was spelled backwards from a list of 40. Cognitive errors included if the word was spelled incorrectly or the participant stated they were unsure after attempting the word (e.g., "pass"). One attempt at spelling was given and then the next word was read off until the test was completed. Different words were used for all trials.[23] Number of dual-task tandem gait trials were consistent with single-task trials.

Soccer Heading Model

A controlled soccer heading paradigm in a laboratory was used as described by Tierney and colleagues.[24] This soccer heading paradigm serves as a functional *in vivo* head impact testing model, which can be used to elucidate mechanisms underlying individual responses to head impact in soccer.[24] A JUGS Soccer Machine (JPS Sports International, Tualatin, OR, USA) launched a standard adult size 5, inflated to full regulation 8 psi, at an angle of approximately 40° and with an initial projection velocity of 25 mph, confirmed via radar gun, to simulate a soccer throw in. After a warm-up with a foam ball, each participant in the experimental group performed 10 headers with a minute of rest in between each header. Two mistrials (e.g., missing ball, ball hitting top of the head) were allowed per participant. The control group sat for 10 mins to simulate the duration of the heading model while limiting movement.

Procedures

Participants completed the health history questionnaire, pre-test PCSS, DPAS, and single and dual-task trials and were fitted with the accelerometer. Participants completed the heading model for their randomly assigned group (determined by coin flip at study inception). Participants were blinded to group assignment until the heading phase of data collection. Following the heading model, participants completed the post-test measurements.

Statistical Analysis

Descriptive and inferential statistics were calculated to evaluate data. Averages from both gait trials were included as dependent variables: time (s), steps, gait errors, and cadence (steps/minute). Dual-task tandem gait dependent variables also included cognitive errors.

To determine the effect of heading group on PROMs and single and dual-task tandem gait parameters three repeated measure MANOVAs were utilized: one for each set of conceptually related and correlated variables, where F value was determined using Pillai's. Trace. Bivariate Pearson Correlations were performed between the dependent variables and the average of linear and rotational acceleration to determine associations between performance and head kinematics. SPSS version 26.0 (SPSS IBM Inc. Armonk, NY) was used for all analyses, with alpha level $p \leq 0.05$.

Results

Participants

Participant descriptive data are presented in Table 1. Post-hoc power analysis of the sample size was approximately 0.50.[25] At pre-test there were no significant differences between groups. The mean 13.5 years of soccer heading experience was above the minimum of five years.

Table 1.
Participant Demographics

Variable	Total (n=12)	Group[a] Heading (n=6)	Control (n=6)	Statistic *p*-value	Effect size[b]
Male	7	4	3	.54	.31
Age (years)	19.62 (3.97)	21.83 (1.94)	22.33 (2.34)	.38	.23
Experience (years)	13.50 (2.8)	14.83 (2.04)	12.17 (3.06)	.69	.95

Note. Age and Experience expressed as Mean (SD)).
a Participants randomly assigned to heading and control groups.
b Effect size benchmarks based on Cohen: Small = .2, medium = .5, large = .8

Patient Reported Outcome Measures

Means ± standard deviation (SD) for pre-test and post-test for each PROM are reported in Table 2. The MANOVA revealed a main effect for test (F = 5.650; p = 0.039). Specifically, there was a significant interaction between time and group, where the heading group scored higher (i.e., more symptomatic) on the PCSS and lower (i.e., better) on the DPAS compared to the control group, $p = 0.042$, $\eta^2 = 0.35$.

Table 2
Participant Reported Outcome Score by Time and Group

Variable	Group[a]	
	Heading (n=6)	Control (n=6)
Pre-Test PCSS	3.67 (4.03)	0.17 (0.41)
Post-Test PCSS	2.33 (4.41)	2.00 (2.10)
Pre-Test DPAS	9.33 (8.24)	1.33 (1.97)
Post-Test DPAS	7.00 (7.95)	2.17 (2.64)

Note. Variable scores expressed as Mean (SD)).
Abbreviation: PCSS, Post-Concussion Symptom Scale, DPAS, Disablement in the Physically Active Scale
a Participants randomly assigned to heading and control groups.

Single-Task Tandem Gait

Pre-test and post-test single-task tandem gait parameter measurements are presented in Table 3. The MANOVA revealed a significant main effect for time (F = 7.765; p = 0.019) and test (F = 945.641; p = 0.000). Specifically, there was an interaction between tests and time, $p = 0.030$, $\eta^2 = 0.65$, where participants executed the task quicker, with more errors and using a faster cadence during post-test. There were no group main effects or interactions, $p = 0.820$.

Table 3
Single-Task Tandem Gait Parameters by Time and Group

Variable	Group[a]	
	Heading (n=6)	Control (n=6)
Pre-Test Time	18.24 (2.68)	18.37 (3.08)
Post-Test Time	16.93 (1.65)	17.58 (2.46)
Pre-Test Error	5.67 (1.13)	4.67 (2.67)
Post-Test Error	6.83 (2.30)	5.00 (2.33)
Pre-Test Steps	23.09 (1.29)	22.83 (2.40)
Post-Test Steps	22.94 (1.32)	22.89 (2.32)
Pre-Test Cadence	77.47 (12.40)	76.43 (16.60)
Post-Test Cadence	82.38 (11.04)	79.56 (15.30)

Note. Variable scores expressed as Mean (SD)). Time (s), cadence reported in steps per minute.
a Participants randomly assigned to heading and control groups.

Dual-Task Tandem Gait

Pre- and post-test dual-task tandem gait measurements are conveyed in Table 4. The MANOVA conveyed a significant main effect for time (F = 5.614, p = 0.039, η^2 = 0.360) and test (F = 3611.129, p = 0.000, η^2 = 1.000). Specifically, gait errors increased, cognitive errors decreased, and cadence increased at post-test. There were no group main effects or interactions, p = 0.444.

Table 4.
Dual-Task Tandem Gait Parameters by Time and Group

	Group[a]	
Variable	Heading (n=6)	Control (n=6)
Pre-Test Time	21.34 (3.33)	22.50 (4.39)
Post-Test Time	20.53 (3.21)	20.68 (4.69)
Pre-Test Error	6.33 (1.63)	4.58 (2.58)
Post-Test Error	5.88 (2.25)	6.22 (2.55)
Pre-Test Cognitive Error	0.75 (0.42)	1.08 (.06)
Post-Test Cognitive Error	0.99 (0.57)	1.00 (.079)
Pre-Test Steps	23.00 (1.38)	22.67 (2.44)
Post-Test Steps	22.94 (1.46)	22.67 (2.57)
Pre-Test Cadence	66.10 (11.54)	64.52 (13.60)
Post-Test Cadence	68.30 (10.92)	69.15 (19.47)

Note. Variable scores expressed as Mean (SD)). Time (s), cadence reported in steps per minute.
a Participants randomly assigned to heading and control groups.

Heading Kinematics

Linear acceleration had a mean of 18.57 ± 2.18g and the rotational acceleration mean was 815.24 ± 147.71°/s². Missing accelerometer data for one participant was filled using the series mean. Significant correlations were found for rotational acceleration and PCSS (r = 0.931, p = 0.007), rotational acceleration and DPAS (r = 0.815, p = 0.048), and linear acceleration and dual-task step (r = 0.891, p = 0.017). Each was a positive correlation whereas head kinematics increased, PROM score and steps increased.

Discussion

The purpose of this study was to assess the effects of an acute bout of soccer headings on single and dual-task tandem gait and PROMs. This study was novel due to the low threshold of impacts measured in a healthy non-concussed population. Our findings suggest that 10 soccer headers resembling a soccer throw in were not sufficient to invoke acute symptomatology or affect either gait assessment, in agreement with previous research.[26] However, there appears to be a learning curve with both heading and control groups beginning to complete the task faster with quicker cadence and compensating by committing more errors. These same changes were also seen in the dual-task assessment with cognitive errors also decreasing further suggesting a learning effect occurred.

Linear and rotational acceleration means were similar to those recorded during games and practices of collegiate soccer players.[27] The strong positive significant correlations between symptom score (i.e., PCSS, DPAS) and rotational acceleration indicate headers with increased rotational acceleration are reporting more symptoms after the heading session. Angular acceleration, more so than linear acceleration, has been identified as more damaging to the brain, causing shearing deformation and greater physiological changes throughout the brain.[28]

In the PROM pre and post-test scores, there were no significant differences between groups. There was one score approximately two standard deviations above the mean for all four PROMs (i.e., pre- and post-test PCSS and DPAS) that was kept in the data set. This may help explain the large variability between heading and control groups.

Clinical Implications

The current study suggests that single and dual-task tandem gait measures that are easily assessed by a clinician are not affected by an acute bout of a laboratory-controlled session of soccer heading. Tandem gait assessments have been used to identify lingering effects of concussion up to 2 weeks post-injury and the cumulative effects of a season.[6,12] While our study found no significant deficits after 10 headers, following a concussive event the dynamic postural changes are greater and result in prolonged deficits that can be measured using single and dual-task tandem gait.[6]

Previous researchers have identified different effects of RHI.[4,7,8,] Negative cognitive changes after a practice involving soccer heading were identified using a tablet-based application.[7] A similar study over the course of a season showed changes in cognitive scores of an n-back task.[29] Though the findings contributed to the understanding of the effects of RHI, they were limited by the use of technology and lack of a functional aspect making it difficult to translate to a clinical or sideline assessment and to an active population. The current study utilized a functional (i.e., gait) and cognitive measure (i.e., backwards spelling) providing a more comparable assessment for an athletic population due to the increased complexity and real-world applicability (e.g., multi-tasking) and found that there were no performance deficits (e.g., slowed tandem gait) or PROMs (e.g., worsening DPAS scores) reported following the acute bout of purposeful soccer heading.

Limitations

It is important to note some limitations of this study. A learning effect seemed to occur with participants starting to walk faster by committing more gait errors. External validity was limited since this study was performed in a controlled environment and may not be applicable for the sideline where there may be other distractions. Additionally, the ball was projected at a relatively slow speed (e.g., throw in). Additionally, lack of deficits in symptomatology, balance, and cognitive abilities could be attributed to the overall low acceleration the ball was projected as compared to if the ball were to be projected at larger acceleration loads (e.g., goal kick). Lastly, this study utilized a small, set window of RHI to replicate a single practice session.

Future Research

Focus of future research should be on functional and translational assessments as well as include field studies to determine the efficacy of performance on the sideline. Additionally, more attention should be on the effects of RHI over a longer time frame such as the course of a season with variable accelerations similar to those seen during a game and/or practice.

Conclusion

In conclusion, RHI did not affect PROMs or single and dual-task tandem gait parameters following an acute bout of purposeful soccer headings. Athletic trainers should be aware that a small, acute bout of RHI may pose little risk to patients. Long-term exposure to RHI and/or larger head accelerations may affect cognitive performance and dynamic postural control. When considering assessment of these potential effects, single and dual-task tandem gait may be a sensitive enough measurement; however, further research surrounding acute and long-term heading still needs to be conducted.

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Conflicts of Interest
The authors have no conflicts of interest to report.

Statement of Contributions
K.B. and M.L. carried out the study, analysis of results, and wrote the manuscript. J.M. contributed to the interpretation of results, the final version of the manuscript, and supervised the project.

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The Long-Term Effects of Outdoor Air Pollution in Urban Environments on Cardiovascular Health: A Global Review

LINDSAY KRAUS[1]; HEATHER M. MURPHY, PHD[1]
[1]Department of Epidemiology and Biostatistics, College of Public Health, Temple University

Correspondence: tuj16109@temple.edu (Lindsay Kraus)

The effects of air pollution on health are listed as a significant cause of death worldwide. Slightly over 3 million deaths per year are due to outdoor air pollution. Studies have shown that short-term increases in exposure to particulate matter have increased the risk of cardiovascular diseases such as myocardial infarction, stroke, and heart failure. However, less is known about the longer-term effects of air pollution on various cardiovascular diseases. The American Heart Association formally recognized PM2.5 as a significant cardiovascular risk factor in 2010. Since then, more prolonged-term exposure to air pollution has been suggested to cause chronic cardiometabolic and cardiovascular problems. The effects of long-term (>1 year) air pollution are significant, but not as much is known about how location affects this exposure. Associations with cardiovascular diseases and their risk factors are often increased in urban settings, which is attributed to a higher concentrations of outdoor air pollution. Potential causes of long-term air pollution concentrations in cities or metropolitan areas come from traffic exposure and traffic intensity. The U.S. Environmental Protection Agency and United Nations have suggested changes in air quality standards, implementation plans, and ways to reduce vehicle emissions specifically to improve human health and reduce the adverse effects of air pollution; however, more work still needs to be done. This review assesses the impact of the global long-term (>1 year) air pollution exposure, specifically in urban environments on cardiovascular health and disease.

***Keywords**: Long-term air pollution, Cardiovascular disease, Pollution exposure*

Introduction

Air pollution is a major global problem. The effect of air pollution has been directly associated with the exacerbated climate crisis as well as detrimental increases in our global public health. The threat of air pollution on health has been listed as a significant cause of death worldwide.[1,2] Over 3 million deaths per year are due to particulate matter less than 2.5uM or $PM_{2.5}$.[3] Air pollution will only increase over time due to the drastic increase in energy production, transportation, waste accumulation, and natural disasters like forest fires[2,3], all of which stress the importance of addressing the health concerns associated with this pollution.

Air pollution is defined as a heterogeneous mixture of gases, liquids, and particulate matter (PM) that is mostly derived from combustion, specifically from fossil fuels.[4] Location is a significant factor that must be considered when discussing air pollution. [5] Urbanized areas have a higher risk of increased air pollution concentrations largely due to energy consumption and exhaust emissions.[6,7,8] Therefore, the urban areas have a higher risk of various cardiovascular diseases (CVDs).[4] The World Health Organization (WHO) has stated about 80% of people living in cities are breathing in air that is over the WHO guideline limit.[6] Specifically, people from lower and middle-income countries suffer from the most exposure and, therefore, are at the highest risk of air pollution-related health risk.[7] Within the U.S., 80.2% of Americans live in an urban area versus the 19.8% that live in a rural area. Interestingly, within the urban areas, 11.2% of Americans are in the lowest socioeconomic status (SES).[9] Globally, the largest gap between the lowest and highest SES exists predominantly in urban settings.[10]

Air pollution can be created in indoor and outdoor environments, such as smoke in a house versus smog in a city, respectively. More specifically, outdoor or ambient air pollution has major implications on human health through the inhalation of toxic particles. The main sources of outdoor air pollution include particulate matter from fossil fuel combustion.[11] Additionally, changes in the composition in ground-level ozone (O_3) due to industrial combustion, traffic, and gasoline can play a major role in outdoor air pollution.[11]PM and NO2 are usually the main contributors to outdoor air pollution; however, ultrafine particles (UFP) have also been associated with increased outdoor air pollution, often due to the combustion reactions[12]. While both outdoor and indoor air pollution are important in regards to global health, in this review, only outdoor air pollution-related to human cardiovascular health will be addressed.

The length of exposure to air pollution is an essential factor related to cardiovascular health as well. Studies have found that short-term increases in exposure to increased concentrations of particulate matter have amplified the risk of cardiovascular diseases such as myocardial infarction, stroke, heart failure, etc..[9] It is known that high amounts of ambient $PM_{2.5}$ increase the risk of CVD, specifically in highly urbanized areas, even in short amounts of exposure time [13], indicating the necessity to fully understand the effect long-term. Specifically, a short-term exposure to outdoor air pollution was strongly associated with the risk factors of ischemic heart disease, specifically in cities[1415] Other health risks may also intensify the risk of susceptibility to air pollution and CVDs, such as obesity. [16]

However, until recently, less was known about the sizeable impact long-term air pollution has on cardiovascular health. The American Heart Association (AHA) formally recognized $PM_{2.5}$ as a major cardiovascular risk factor in 2010.[10] Since then, long-term exposure to air pollution has been suggested to cause chronic cardiometabolic problems such as diabetes.[11] However, there is still a lack of information on the effect of long-term outdoor air pollution on cardiovascular health, specifically in urban locations such as cities or metropolitan areas with higher concentrations of air pollution.

In this review, short-term air pollution is described as less than one year of exposure, while long-term air pollution is three or more years of exposure. This review will outline the latest research from the last twenty years linking the extended exposure to air pollution in metropolitan areas to cardiovascular disease on a global scale.

Methods

This scoping literature review used articles found through the PubMed and Google Scholar databases to answer the initial question, "how does long-term outdoor air pollution found in urban environments affect cardiovascular health?" The initial search examined keywords displayed in Table 1 found in the title and abstract of retrieved papers as well as the index terms that describe the articles. All relevant reviews and articles were exported to Zotero for further examination and comparison. In the screen, all articles were scanned for titles based on the relevance of inclusion and exclusion criteria specified in

Table 1
Search terms used in systematic review of literature on long term outdoor air pollution found in urban settings on cardiovascular health, 2000-2021

Question	**Cardiovascular Terms**	**Air Pollution Terms**	**Location Terms**
How does long term outdoor air pollution found in urban environments affect cardiovascular health?	"cardiovascular disease," "heart," "myocardial infarction," "heart failure," "ischemic heart disease," "hypertension"	"long-term air pollution," "outdoor air pollution," "ambient air pollution" "particulate matter," "UFP," "nitrogen dioxide," "ozone"	"cities", "urban setting", and "metropolitan"

Table 2, which also helped identify our Population, Exposure, and Outcome framework. The inclusion criteria consisted of studies that took place in defined cities or metropolitan areas studying outdoor air pollution effects on cardiovascular health for greater than one year. Exclusion criteria included separate, non-cardiovascular-related health effects such as renal function, lung function, and brain function as well as suburban or non-metropolitan specific locations. Any studies that were conducted for less than one year were considered short-term exposure and were not included.

Additionally, we searched for recent articles that researched over the last thirty years to emphasize the latest long-term studies; therefore, research studies conducted between 1990 and 2021 were included. We also examined broader primary studies to help narrow our search for more recent and specific articles. We examined the reference list of these key papers to identify additional studies for more specific articles. Furthermore, to find grey literature on the topic, we individually searched for key authors in the field that were established in the original search, key agencies or organizations that often conduct relevant research, and key journals that have an index or database of related topics. Additionally, we referenced the PRISMA flowchart and checklist for a scoping literature review[17]. From this, a total of 9650 articles were found through database searching. After duplicates were removed and screened through titles and abstracts, approximately 173 articles were eligible. From this group, the articles were fully scanned and 59 were used for this review.

Table 2
Inclusion and exclusion criteria used during systematic review of literature for screen

Question	**Population/Location**	**Air Pollution**	**Health Effect**	**Include**
How does long term outdoor air pollution found in urban environments affect cardiovascular health?	Must be representative of an urban setting	Identifies long term air pollution exposure (longer than three months)	Addresses an effect on heart or cardiovascular health	If it specifies the length of air pollution exposure in an urban environment on cardiovascular health

Results

Long-Term Air Pollution and CVD

Long-term exposure to $PM_{2.5}$ and ozone (O_3) has been connected with the progression of CVDs. Recently, long-term exposure to air pollution resulted in increased heart rate variability, blood pressure, vascular tone, blood coagulation, and atherosclerosis.[18] A study through the AHA found that people exposed to $PM_{2.5}$ and ozone over five years had poorer health one year following a myocardial infarction (MI). This was correlated with an added risk of death due to increased morbidity and mortality as well as worsened symptoms within the following five years.[19] Using cohort studies, An et al.. summarized that long-term exposure to air pollution resulted in a significantly higher risk of CVD (1.24%) compared to short-term exposure, which was hypothesized to be because of the compounding effects of extended air pollution exposure. [18] Another study found that cardiopulmonary death was associated with fine PM ($PM_{2.5}$) and sulfur dioxide (SO_2) pollution. Interestingly, Pope et al. concluded that every ten microgram increase in $PM_{2.5}$ air pollution was associated with a 4% increased risk of cardiopulmonary mortality and, therefore, contributed to the adverse effects of long-term exposure on health.[20]

A critical study by Miller et al. found that postmenopausal women had an amplified risk of CVD and death associated with cardiovascular issues because of long-term exposure to fine PM. In addition, they found that there were different risks and exposures to women in cities. [21] Another group found that the elderly community (65 years or older) are more at risk for the adverse effects of air pollution on cardiovascular health. A study of the elderly population in Taiwan found that added long-term exposure to ambient air pollution causes changes in blood pressure as well as blood sugar and blood lipids on older members of the population. [22]

How Extended Exposure to Outdoor Air Pollution Affects Cardiovascular Health

To better understand how to treat and prevent CVD associated with air pollution, it is essential to determine how air pollution causes an increase in disease. Some studies have explored how fine particulate air pollution causes a variety of CVDs through inflammatory mechanisms. One study examined increased pulmonary and systemic inflammation. This inflammation is associated with breathing in the particulate matter associated explicitly with air pollution. This escalation in the inflammation from air pollution exacerbated atherosclerosis and decreased cardiac function.[23] Another group studied environmental PM in an atherosclerotic mouse model and found that long-term exposure to this air pollution changed the vascular tone and significantly increased vascular inflammation leading to a CVD such as atherosclerosis.[24]

Long-term Air Pollution in Urban Settings

The effect of long-term air pollution is significant, but not as much is known about how location affects this exposure. In cities, there is an escalation in traffic and motor emissions strongly associated with air pollution.[25] This kind of air pollution often consists of elemental carbon, ultrafine particles, and nitrogen oxides.[25] An initial study found that there was a strong association of increased fine PM air pollution that led to increased mortality in six different United States cities, including Steubenville, St. Louis, Harriman, Watertown, Topeka, and Portage[26]. These cities were chosen because of the known air pollution in the area, with

Steubenville being the worst and Portage being the best. Specifically, the authors found an increase in cardiopulmonary diseases in over eight thousand adults over 15 years.[26] Later in 2006, a similar study found that increased $PM_{2.5}$ was associated with cardiovascular mortality, and when that exposure was reduced, there was a decrease in mortality.[27]

High blood pressure or hypertension is a significant risk factor for CVD.[28] A study found that long-term exposure to PM led to an increase in arterial blood pressure. This association was significantly amplified in urban settings, which was attributed to an increased concentration of $PM_{2.5}$. This outcome was independent of ethnic groups or seasonal changes.[29]

Some confounding variables have been suspected in outdoor air pollution studies. Specifically, changes in season and temperature have been thought to affect air quality.[24] A study examined the risk in cities over various seasons and found the risk of mortality related to outdoor air pollution was not significantly different in above-average or below-average temperatures. The risk was the same in cities in drier climates as well as humid climates. This indicated that the weather or temperature changes were not responsible for increased mortality related to air quality or condition.[30]

As shown in Table 3, there are various pollutants commonly found in outdoor metropolitan environments that intensify cardiovascular problems. However, Cesaroni et al. suggested that air pollutants, specifically from traffic, including NO_2 and $PM_{2.5}$, cause the most severe and persisting cardiovascular problems. Specifically, traffic-related air pollution is defined as NO_2 and $PM_{2.5}$ that is uniquely augmented during rush hour periods, and is also found in vehicular emissions.[31] In Rome, the long-term exposure to air pollution was attributed to increased exposure to NO_2 and $PM_{2.5}$, which was associated with a greater number of incidents of ischemic heart disease.[32] A similar result was also found in major cities in Greece, where CVD morbidity was associated with prolonged exposure to traffic-related air pollution.[33] In a cohort study from Norway and the United Kingdom, traffic air pollution was also associated with increased cardiovascular mortality. Specifically, in high traffic areas, the long-term exposure to particulate air pollution was connected to more cases of CVD. Additionally, even air pollution levels lower than the current European air quality standards were linked to CVD risk.[34] In general, air pollution in major European cities is caused by traffic pollution, which is resulting in elevated risks of CVDs. Finally, Beelen et al. created a multicenter program called European Study of Cohorts for Air Pollution Effects (ESCAPE), which assessed long-term air pollution on mortality. This study assessed large cities in Europe, some of which include Oslo, Stockholm, Augsburg, Rome, and San Sebastian, and found an increase in risk factors for cardiovascular diseases. Overall, this study summarized the massive negative effect on heart health due to air pollution in cities, specifically in Europe.[35]

In the Netherlands, extended exposure to traffic-related air pollution was linked to an added risk of cardiovascular mortality. The study measured black smoke, nitric oxide, sulfur dioxide, and $PM_{2.5}$. They measured local or home outdoor exposure compared to urban exposure based on geographic information systems to determine the intensity of traffic exposure in the respective areas. They discovered that traffic intensity, specifically near the home, was associated with a $10ug/m^3$ increase in black smoke, NO, and $PM_{2.5,}$ which was related to cardiovascular mortality and lung cancer. Downward et al. found that long-term exposure to ultrafine particles (UFP) was strongly associated with an increase in CVD. Specifically, the authors found that UFP was often underestimated, due to the current emphasis on PM. This long-term exposure study in Amsterdam found increased incidents of myocardial infarction as well as heart failure associated with UFP[12].

There is an apparent exacerbated risk of CVD because of outdoor urban air pollution, but there are also populations that are more at risk, which must be considered. For example, a study found that long-term air pollution exposes the elderly to an increased hospital admission rate for cardiac disease.[37] A study focused on

Table 3.
Comparison of outdoor air pollutants commonly found in cities[20]

Types of Outdoor Air Pollution found in Cities	Source/Composition	Adverse Health Effects	WHO guideline level
Particulate Matter 2.5uM or 10uM ($PM_{2.5}$ or PM_{10})	Components of sulfates, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water suspended in the air, often from combustion	PM_{10} can enter lungs through inhalation causing cardiovascular and respiratory problems. $PM_{2.5}$ can enter lung barrier and blood system causing cardiovascular and respiratory problems	PM_{10} 20 μg/m^3 annual mean 50 μg/m^3 24-hour mean $PM_{2.5}$ 10 μg/m^3 annual mean 25 μg/m^3 24-hour mean
Nitrogen Dioxide (NO_2)	Aerosols, component of $PM_{2.5}$, emission from combustion for heat, power, engines of vehicles and ships	Causes inflammation of airways, bronchitis in asthmatic children, reduced lung function	40 μg/m^3 annual mean 200 μg/m^3 1-hour mean
Sulfur Dioxide (SO_2)	Produced from combustion of fossil fuels (coal and oil) mostly for heating power of motor vehicles, common component of acid rain	Reduced lung function, eye irritation, inflammation of respiratory tract, increased risk of pulmonary infection, increased risk of cardiovascular disease	20 μg/m^3 24-hour mean 500 μg/m^3 10-minute mean
Ozone (O_3)	Ground level component of photochemical smog created when sunlight reacts with other air pollutants	Causes breathing problems, asthma, reduced lung function, enhanced lung diseases	100 μg/m^3 8-hour mean

metropolitan areas of Greece found that long-term exposure to traffic-related air pollution caused an added risk of fatal and nonfatal ischemic heart disease and stroke. Importantly, they found that this CVD risk was higher in women and younger children.[33]

Urban, traffic, and industrial-related air pollution is the biggest issue in large cities in Asia.[38] In Tianjin, Shenyang, Taiyuan, and Rizhao, air pollution levels are significantly higher than even the upper limits of the WHO guidelines.[39][20] These increases in $PM_{2.5}$ are associated with higher risks of CVD mortality. Importantly, the more significant impact on CVD mortality was associated with a longer duration of exposure.[40] Air quality has not only been associated with a decline in human health but also in food instability in China. In six sectors of China, the $PM_{2.5}$ and the O_3 pollutants were found to be detrimental to human health as well as crop production leading to an overall reduction in health.[41] Additionally, a study from Seoul, South Korea found that long-term exposure to $PM_{2.5}$, specifically a 1μg/m^3 increase over an average of seven years caused a 36% increase in cardiovascular events[42]. Importantly, these cardiovascular events, which included heart failure, myocardial infarction, and stroke, occurred in individuals who had no previous cardiovascular issues, emphasizing the staggering implication of long-term air pollution on heart health.[42]

Furthermore, India has a considerably higher prevalence of elevated levels of urban air pollution. This is associated with the country's increased motor vehicle activity as well as industrialization. A group analyzed 59 independent studies of short (hours, days, weeks) and long-term (months, years) ambient air pollution cases in India. They determined that long-term air pollution was strongly associated with asthma, heart attack, cardiovascular mortality, and premature mortality. The majority of health problems related to air pollution were caused by $PM_{2.5}$.[44]

In the United States, outdoor air pollution has been associated with increased cardiovascular death, specifically in urbanized areas.[45] A comprehensive study examined 90 U.S. cities for PM_{10} and found an increase in mortality, specifically cardiovascular and respiratory mortality.[46] Another study analyzed 88 of the largest urban areas in the United States for over eight years and analyzed all causes of mortality. They found that variations of PM_{10} were attributed to cardiovascular and respiratory mortality compared to all other causes of death.[47] The same group examined five outdoor air pollutants relative to mortality in 20 of the largest cities in the United States over the same eight-year period. They found that the PM_{10} was the air pollutant most strongly associated with cardiovascular mortality. In fact, for every 10μg per cubic meter increase in PM_{10}, there is a rise in cardiovascular-related death.[48] Another study analyzed data from 13.2 million U.S. residents within a six-mile radius of a $PM_{2.5}$ monitor. They found that in eastern and central U.S. urban centers, a 10μg per cubic meter increase of $PM_{2.5}$ over six years was associated with a 6.8% increase in mortality.[49] Even with this information, the United States Environmental Protection Agency (US EPA) standards are not limiting enough. A study examined hospitalization and congestive heart failure cases in seven U.S. cities over 13 years. They found that even air pollution levels below the EPA standard still resulted in additional hospital admission rates for congestive heart failure in people above the age of 65.[50]

Across the globe, it is clear that increased long-term exposure to air pollution has a significant impact on cardiovascular health. However, there is still not much understood about how to reverse or lessen the adverse health effects of air pollution.

Discussion

How to Reduce Long-term Air Exposure Risks in Urban Settings

Long-term exposure in urban areas is a significant risk factor for various CVDs. The United States Environmental Protection Agency (US EPA) created an annual National Ambient Air Quality Standard (NAAQS) in 1997 specifically for $PM_{2.5}$ that would require a decrease of 1μg per cubic meter in $PM_{2.5}$. A study examined the rate of cardiovascular mortality based on changes in the $PM_{2.5}$ before and after the changes in the NAAQS guidelines in over 180 countries across the globe over 20 years. Interestingly, they found that for every 1μg per cubic meter decrease in $PM_{2.5}$ lead to about a 1.10% decrease in cardiovascular-related deaths.[51]

Langrish et al., found that reducing personal exposure to PM by wearing masks that have a polypropylene filter that filters airborne PM and does not change ambient gas did improve the health of patients with coronary heart disease.[52] Car filters have also been suggested as a possible recirculatory way to reduce airborne nanoparticles. The filters help recirculate the air to minimize nanoparticle concentrations below dangerous levels. The filters can reduce the concentration of pollutants less than nanoparticle concentration accumulated after three minutes of driving in heavy traffic.[53] Even low-efficiency filters have been shown to protect from traffic PM exposure effectively.[53] Exhaust PM traps on specific car engines have also been successful at decreasing PM exposure. These traps have even been used as a biomarker for CVD improvement.[54]

As of 2019, there are studies designed to understand how outdoor air pollution affects cardiovascular health in specific populations. The Reducing Air Pollution in Detroit Intervention Study (RAPIDS) is analyzing a senior citizen community in Detroit for CVDs, increased blood pressure, and vasoconstriction[5554]. This area has been strongly linked to high levels of outdoor air pollution, specifically $PM_{2.5.}$ The group is using low efficiency and high-efficiency air filters in various conditions to assess if they can help improve cardiovascular health outcomes for high-risk populations.[54] Continued studies such as this would be beneficial for an understanding of cardiovascular global health relative to outdoor air pollution.

Addressing Issues Regarding Outdoor Air Pollution

There is a dire need for change when it comes to PM and other air pollutants. The US EPA has suggested changes in air quality standards, statewide implementation plans, and ways to reduce vehicle emissions[56], but more work still needs to be done. For example, improvements have been made relative to traffic pollution through emission controls. Specifically, there are requirements for fewer tailpipe emissions as well as reduced crankcase emissions (combustion-related gases from the engine) through mandatory vehicle emission testing in the US[25], however, universally these measures are still lacking.

Globally, the WHO Air Quality Guidelines (AQGs) are updated annually to be used as a baseline and reference for world leaders and lawmakers to make decisions for air quality limits and management.[57] The primary air pollutants the AQGs address included the particulate matter of various sizes, ozone, nitrogen dioxide, and sulfur dioxide. More recently, the guidelines have taken the length of exposure more seriously by including the impact of the duration of exposure in the AQGs as a way to emphasize the drastic need to update laws and educate the public.[57]

These guidelines are meant to aid and advise world leaders; however, the impact and use of the guidelines are not followed equally across the globe. Joss et al. discovered that air quality standards for ambient outdoor air pollutants from 170 countries out of the 194 analyzed had varied levels of air quality standards, most not complying with the WHO guidelines. Moreover, 57 countries did not have any air quality standards at all.[58] This indicated not only a need for a better global air quality plan but also a need for better universal approaches to improve air quality.

More recently, the United Nations General Assembly created the global 2030 Agenda for Sustainable Development in 2015. One of the main goals created by this group was to adequately address air pollution and emphasize the detrimental effect on human health.[59] The current seventeen Sustainable Development Goals (SDGs) do not have an individual goal for air standards or air pollution. So, this 2030 Agenda was put forth to create a global air quality standard by focusing on international law about the atmosphere and global air pollution.[59]

Conclusions

Overall, the long-term exposure of outdoor ambient air pollution in urban settings is an increased hazard and risk for global health, specifically for cardiovascular health. There is significant evidence of the cardiovascular risk associated with outdoor air pollution in urban environments. Specifically, long-term exposure (more than three months) to outdoor air pollution leads to an amplified potential for a variety of CVDs and their risk factors. Cities and metropolitan areas have an increased susceptibility to the negative effects of outdoor air pollution because of added exposure to traffic and motor emission pollution, which leads to increased concentrations of dangerous air pollutants. Mechanistically, an increase in this outdoor air pollution has been shown to escalate inflammation in the heart and vasculature, which causes exacerbated effects of CVD. Yet, the detailed mechanism and side effects are still unknown.

There are still many questions that need to be answered in regards to the specific concentrations of various air pollutants and their effects on cardiovascular health, specifically in vulnerable populations worldwide. A comprehensive understanding of all the various outdoor air pollutants, their concentrations in urban environments globally, and their toxicities, would provide insight into why outdoor air pollution is so harmful in certain areas and what can be done to prevent further damage. There are still many unknowns regarding the extended exposure to outdoor air pollution on cardiovascular health,.[38] A better understanding of the mechanism could allow for more targeted interventions for preventing or lessening the adverse effects on human health. Finally, there is still a need for universal policies on air quality standards that are implemented and followed globally.

Conflicts of Interest

The authors have no conflicts to disclose.

Statement of Contributions

LK had the idea for the article under the guidance of HM. LK did the literature review and writing. HM provided critical revisions and oversight.

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