The Journal of EMERGING SCIENTISTS

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To ensure compliance with safeguarding protocols, students' last names have been omitted from this journal. Schools or institutions seeking to verify the authenticity of any entry are encouraged to contact our high school office directly.

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Foreword

Welcome to the second edition of the *Journal of Emerging Scientists*. With this publication, we celebrate not only the individual achievements of our student researchers but also the continued growth of Independent Science Research at SSIS. What began as an opportunity for students to pursue questions of personal scientific interest has developed into a program that asks them to think, work, and communicate with increasing independence, discipline, and purpose.

The research presented in this issue represents many months of sustained effort. Each project began with curiosity: an observation, a concern, a question, or a problem that invited further investigation. From there, students moved into the demanding work of research design, background reading, data collection, analysis, revision, and scientific writing. Along the way, they encountered the realities of authentic inquiry: uncertainty, imperfect methods, unexpected results, limitations, and the need to make careful decisions based on evidence rather than assumptions.

That process matters. Scientific research is rarely simple or linear, and the work in this journal reflects that truth. These students have had to refine their ideas, reconsider their approaches, seek feedback, and persist as their investigations have become more complex than they first imagined. In doing so, they have developed not only stronger scientific understanding, but also the habits of mind that serious inquiry requires: patience, precision, skepticism, resilience, and intellectual honesty.

Within these pages, you will find a wide range of investigations across areas such as materials science, biochemistry, environmental science, behavior science, and other fields of student interest. The diversity of topics reflects the breadth of curiosity within our learning community, while the completed papers demonstrate the students' growing ability to connect personal questions with broader scientific concepts and methods.

This journal also serves an important purpose beyond showcasing final products. It makes students' thinking visible. It allows readers to see young researchers engaging with evidence, constructing explanations, acknowledging limitations, and contributing their voices to scientific conversations. For many students, this publication marks an important step in seeing themselves not simply as learners of science, but as people capable of participating in the work of science.

The second edition of the *Journal of Emerging Scientists* is therefore both a record and an invitation. It records the effort, growth, and achievement of this year's researchers. It also invites the SSIS community to recognize the value of independent inquiry and to engage with the questions our students have chosen to pursue.

The editorial team extends its sincere gratitude to the faculty mentors who have guided students throughout this process with expertise, encouragement, and care. We also thank the many individuals whose support has made this edition possible.

We hope you find this issue of the *Journal of Emerging Scientists* thoughtful, engaging, and inspiring. It offers a meaningful glimpse into the research culture continuing to take shape within the Independent Science Research program at SSIS.

Happy reading!

The Editorial Team

Student Bios

In addition to Independent Scientific Research, **Angela**, a senior at SSIS, has taken AP Economics, AP Statistics, and AP Calculus BC. Angela's research project focuses on **discovering whether being in the presence of animals, specifically cats, has a significant effect on an individual's physiological responses to stress after the interaction**. While conducting her research, Angela faced challenges such as coordinating with a local cat cafe to host her experiment and sorting data while maintaining confidentiality. This helped her learn to communicate professionally and conduct experiments with integrity and ethics. Besides her love for animals, Angela enjoys attending pottery workshops and trying new cafes. This fall, Angela plans to study Business Administration with a concentration in Finance at the University of Southern California and then to pursue a career in high finance.

A senior at SSIS, **Bao Anh** has taken AP Calculus BC, AP Physics C, and IB Mathematics AA HL. For her Independent Scientific Research project, she focused on **mitigating the harmful effects of acidic soil on certain plant species**. During her investigation, Bao Anh worked to ensure the accuracy and fairness of the experiments, which guided her to innovate and persevere. Besides being a nature enthusiast, Bao Anh enjoys playing the piano and electric guitar. After SSIS, Bao Anh plans to study Actuarial Science to become an actuary.

Brian is a senior at SSIS who is currently taking AP Chemistry, AP Biology, and AP Physics 1. Inspired by his motivation to improve his overall health, Brian's Independent Scientific Research project focuses on **how different macronutrient compositions affect high school students' perceptions of their athletic performance during high-intensity exercise**. While conducting this investigation, Brian faced challenges with data collection and with ensuring participants adhered to their assigned dietary conditions, which taught him perseverance and deepened his understanding of self-report bias. This fall, Brian plans to study neuroscience at the University of British Columbia to pursue a career working in a medical lab.

Chun Yu is a senior at SSIS. In addition to Independent Scientific Research, he is currently taking AP Physics C: Mechanics, AP Calculus BC, and AP CSA. Curious about the psychology of money, Chun Yu's research project focuses on **how payment methods psychologically influence teenagers' spending in response to the exponential growth of digital payments**. Chun Yu faced challenges in data collection and analysis during his research, which taught him to use different data analysis methods and to reach out to participants, both in person and online. When not studying, Chun Yu enjoys playing badminton. This fall, he plans to study Finance at the Hong Kong University of Science and Technology with the goal of working in Fund Management.

Ha Trung is a senior who is currently taking AP Chemistry, Environmental Science, and Independent Scientific Research. Inspired by his curiosity about robotics, Ha Trung's research project focuses on the **correlation between PSI and soft-robot bending, as well as their applications**. While conducting his research, Ha Trung faced challenges in fabricating the actuator, which taught him perseverance and resilience in fixing the air leak. Outside the classroom, he enjoys taking part in VEX Robotics. In the future, Ha Trung will study Mechanical Engineering to pursue a career in Engineering.

In addition to Independent Scientific Research, **Huichan**, a senior at SSIS, is also taking AP Biology and previously took AP Statistics. Huichan's research project focuses on **answering the question "To what extent does nationality shape athletes' sport preferences and affect their performance levels?"** He was curious to see if there were setbacks or benefits for different athletes from different backgrounds. While conducting his research, Huichan faced challenges in narrowing down reliable and relevant data sources, which taught him perseverance and strengthened his ability to critically evaluate information and avoid self-selection bias. When not at school, Huichan enjoys playing basketball and hanging out with friends. He plans to study veterinary science or biology and become a vet, researcher, or health sciences professional.

Jeremy is a senior at SSIS who is currently taking AP Chemistry, AP Biology, AP Statistics, and Independent Scientific Research. Inspired to know more about how excessive sweating affects adolescents beyond physical symptoms, Jeremy's research project **examines the psychological and social impacts of hyperhidrosis in teenagers, aiming to understand its effects on quality of life and mental health**. Jeremy's research taught him the importance of critical analysis and recognizing research limitations when he faced challenges in collecting reliable self-reported data and accounting for potential bias. Outside of school, he enjoys playing tennis, discovering new interests, and working out. After graduating, Jeremy plans to study Finance so he can work in financial management.

Jolie is a senior at SSIS. She has taken AP Biology, AP Statistics, and Environmental Science, which inspired a particular **curiosity about bacteriology and microorganisms**. Jolie has also taken a first-aid workshop led by a local Vietnamese Medical University, which deepened her **passion for first aid and wound care**. While conducting her Independent Scientific Research project, Jolie faced challenges with biohazards and regulating bacterial growth, which taught her problem-solving and laboratory skills. Beyond her interest in science, Jolie also enjoys art and music. Jolie plans to study Business and Hospitality Management at New York University and then pursue a career in consulting.

Student Bios

Khang is in Grade 12 at SSIS. In addition to Independent Scientific Research, he has taken AP Chemistry, AP Biology, and AP Statistics. Driven by his passion for fitness and nutrition, and by his personal experiences with conflicting beliefs about food safety, Khang's research investigates **how different protein sources, especially plant-based and whey protein, affect muscle growth and overall health. His goal is to connect scientific evidence with public perceptions to promote safe, effective dietary choices**. During his research, Khang encountered difficulties understanding sometimes contradictory studies, which improved his critical thinking and highlighted the importance of assessing bias in scientific reports. When not in school, Khang enjoys exercising and staying active. This fall, he will study Food Science at Purdue University, aspiring to become a chef who combines culinary arts with scientific expertise to enhance dining experiences.

Michael is a senior at SSIS who has taken AP Chemistry, AP Biology, AP Calculus BC, AP Statistics, and Environmental Science. Inspired by his personal curiosity as a fencing athlete, Michael's Independent Scientific Research project focuses on the **impact of sports drink composition on adolescent athletes' performance**. Michael faced challenges with data collection and collection methods during his research, which taught him perseverance and the importance of seeking support when needed. Outside the classroom, he enjoys hiking, camping, and river tracing. This fall, Michael will study Environmental Science at the University of California, Los Angeles (UCLA) with the goal of becoming an Environmental Engineer or Hydrogeologist.

Minh-Khang (MK) is a senior at SSIS. He has taken AP Biology, AP Psychology, and AP Economics, in addition to Independent Scientific Research. Inspired by his love for sports and his recovery from an ACL injury, MK's research project **examines whether high school athletes recovering from long-term injuries (≥ 3 weeks) experience significantly higher sport anxiety and psychological barriers when returning to sport compared to those recovering from short-term injuries (< 3 weeks)**. While conducting his research, MK faced challenges with limited participant recruitment—particularly an inability to obtain a sufficient number of participants—and an overall small sample size, which limited statistical significance. This taught him perseverance and the importance of careful experiment design. Beyond academics, MK enjoys playing soccer and hanging out with friends. This fall, he will study kinesiology at the University of Virginia with the goal of working in sports physical therapy.

Nam, a senior at SSIS, has taken AP Physics, AP Chemistry, and AP Calculus. His Independent Scientific Research project was inspired by his interest in aviation. **Nam investigated how rainfall intensity affects the aerodynamic efficiency of fixed-wing aircraft and explored design adaptations to improve flight performance and fuel efficiency in Vietnam's tropical climate**. Nam's research was challenged by limited access to simulations and experimental data. This taught him perseverance and adaptability when working with real-world constraints. Besides being an aviation enthusiast, Nam enjoys basketball. This fall, he will study Aerospace Engineering at the University of California, Irvine, and ultimately wants to work in the aviation industry.

Ngan is graduating SSIS this year. Besides Independent Scientific Research, she is taking courses in physical and environmental science. Inspired by her passion for fashion and sustainability, she strives to provide solutions that facilitate them. Ngan's research project focuses on **ways to encourage fast fashion while making it sustainable**. These include testing fabrics that could be more sustainable alternatives, such as cotton, linen, and polyester, through composting. While conducting her investigation, Ngan faced challenges with collecting samples, which taught her resilience as she had to think quickly on her feet. After graduating from SSIS, Ngan plans to study Business and work in Business Management.

Tristan is a senior at SSIS. Besides Independent Scientific Research, he is taking AP Physics C and AP Calculus. Inspired by his passion for the Kerbal Space Program, Tristan's research project focuses on **the extent to which regenerative cooling systems can be implemented on next-generation hypersonic aircraft**. While conducting research, Tristan encountered frequent divergence issues in steady-state CFD simulations. This required him to develop patience, as he meticulously refined his mesh and solver parameters to ensure a stable, physically accurate solution. Beyond academics, Tristan enjoys volleyball and going to the gym. This fall, he plans to study Mechanical Engineering at Cal Poly SLO and ultimately work at NASA.

To what extent does cooling channel geometry affect thermal management feasibility in regenerative cooling systems for hypersonic propulsion applications?

ABSTRACT

Regenerative cooling, in which cryogenic propellant circulates through channels embedded in the engine wall before combustion, is the dominant thermal protection mechanism in modern liquid rocket engines and a candidate for next-generation hypersonic propulsion systems. Despite an established body of literature on individual channel geometries, few studies systematically evaluate how varying channel geometry affects thermal feasibility operating under combustion conditions representative of high-performance liquid rocket propulsion at 100 bar and 3,500 K, serving as a proxy for hypersonic propulsion thermal loads. This study investigates the extent to which cooling channel geometry, represented by varying convective heat transfer coefficients (h) and coolant reference temperatures (T_ref), affects maximum wall temperature in a GRCop-42 regeneratively cooled rocket nozzle operating at 100 bar and 3,500 K. Ten steady-state Conjugate Heat Transfer simulations were conducted using SimScale, with h varied from 0 to 80,000 W/m²K and T_ref from 112 to 150 K across three parametric groups. Maximum wall temperature ranged from 1,572 K in the fully finned configuration to 3,500 K in the uncooled baseline — a reduction of 1,928 K or 55.1%. Maximum convective wall heat flux ranged from 55.96 to 88.49 MW/m², consistent with established literature values for high-pressure liquid rocket engines. No configuration reduced maximum wall temperature below the GRCop-42 operational limit of 1,073 K, the Inconel 718 limit of approximately 1,200 K, or the titanium alloy limit of approximately 600 K. The null hypothesis is fully rejected and the alternative hypothesis fully supported. These findings suggest that regenerative cooling geometry alone is insufficient for hypersonic aircraft thermal management under the conditions tested, and that supplementary methods such as film or transpiration cooling would be required in any practical aircraft application.

Keywords: Regenerative cooling, conjugate heat transfer, CFD, hypersonic propulsion, GRCop-42, liquid methane, cooling channel geometry

INTRODUCTION

Context

As the aerospace industry pushes propulsion systems toward hypersonic speeds (generally defined as flight exceeding Mach 5), thermal management becomes an increasingly crucial challenge to face. At these velocities, aerodynamic heating and combustion-related heat impose extreme thermal loads on the engine structures that conventional cooling technologies cannot reliably absorb. The severity of these loads varies between propulsion types. In scramjet combustor walls operating in air-breathing mode, heat fluxes range in the 1-20 MW/m2at low static pressures (0.065-0.1 MPa), while closed-cycle liquid rocket engines face the most extreme conditions. Heat fluxes of 10-160 MW/m2 at chamber pressures exceeding 10-20 MPa, with the Space Shuttle Main Engine chamber reaching approximately 160 MW/m2 at the throat (Luo et al., 2021). In both cases, chamber temperatures can reach up to 3,500 K, and without adequate cooling, structural failure of the engine is inevitable. Regenerative cooling (where cryogenic propellant is circulated through channels in the engine wall before combustion) is the dominant thermal management method in modern liquid rocket engines. Liquid methane has emerged as a particularly promising coolant due to its compatibility with LOX/methane propulsion cycles, its high specific heat capacity, and its availability as both fuel and coolant in a single fluid system. At supercritical pressures, methane exhibits variable thermophysical properties that complicate heat transfer prediction and channel design (Haemisch et al., 2021).

The challenge of hypersonic thermal management has been characterised by industry practitioners as a cascade problem: extreme aerodynamic surface heating constrains material selection to only those capable of surviving the thermal environment, which in turn necessitates active cooling systems that introduce operability, reusability, and engineering complexity (Victor H., personal communication, 2026). The present study addresses the second stage of this cascade — quantifying the thermal loads that any candidate active cooling system must overcome.

Literature Synthesis

The geometry of internal cooling channels is the primary engineering lever available to designers seeking to control how effectively a coolant absorbs heat from the surrounding wall. This effectiveness is quantified by the convective heat transfer coefficient, h (measured in W/m²K), which expresses how many watts of heat are transferred per square metre of wall surface for every degree of temperature difference between the wall and the coolant. A higher h means the coolant pulls heat more aggressively from the wall and the coolant. The primary way to increase h is to change the shape of the channel the coolant flows through.

One of the most studied geometric parameters is the channel aspect ratio, defined as the ratio of channel width to channel height. A narrow, tall channel forces the coolant into closer contact with the hot wall and generates more turbulent flow, which disrupts the insulating boundary layer of slow-moving fluid that naturally forms near any surface. Ulas and Boysan (2013) demonstrated through numerical analysis of a 300 kN rocket engine that increasing channel aspect ratio progressively reduced maximum wall temperature, though at a higher pressure drop. Pressure drop is the resistance the coolant pump must overcome to push fluid through the channel. This is a critical constraint, especially for aircraft applications, because pump power may be limited. Their study found that variable cross-sectional area channels, which widen toward the nozzle exit to manage the pressure drop, reduced pressure drop by 64% with only a small 2 K increase in wall temperature, illustrating that geometry can be optimized to balance thermal and hydraulic performance simultaneously.

Beyond aspect ratio, surface enhancements such as fins and ribs introduce additional turbulence by physically disrupting the flow. Fins are protrusions extending from the channel wall into the coolant stream, while ribs are periodic ridges running across the channel floor; both act to break up the thermal boundary layer and force cooler fluid into contact with the hot wall. Gibreel et al. (2025) compared four channel configurations of increasing complexity in a hydrogen-cooled rocket engine: a smooth baseline, a partially finned design, and a fully finned design in which fins covered the entire inner surface. The fully finned configuration achieved a 14% reduction in maximum wall temperature and a 25.37% improvement in thermal performance factor. The thermal performance factor is a combined metric that accounts for both heat transfer gain and pressure drop penalty.

Channel path geometry, defined as the overall routing of the cooling channel through the engine wall, provides an additional degree of freedom for the engine. Rather than running channels in straight axial lines from inlet to outlet, a spiral configuration wraps the coolant helically around the thrust chamber, increasing total contact length between coolant and the wall without changing channel cross-section. Lv et al. (2023) developed and validated a one-dimensional heat transfer model for spiral-channel cooling and found that spiral channels reduced maximum wall temperature by 8.5% compared to straight channels of identical dimensions under the same thermal boundary conditions. When channel width, height, pitch, and inner wall thickness were further optimized, using a response surface algorithm, maximum wall temperature fell by 29.8% relative to the unoptimized straight channel baseline.

Beyond wall temperature reduction, the concept of thermal recycling adds a further dimension to cooling system design. Rather than treating heat absorbed by the coolant as a waste, Jeon and Park (2024) modelled a closed-loop approach in which the thermal energy gained by the coolant as it passes through the channels is fed back into the combustion inlet conditions, improving thermodynamic cycle efficiency. Across four engine cycle types using LOX/methane propellant, this thermally coupled approach predicted specific impulse improvements of 1.5-2% over conventional decoupled cooling models. For aircraft applications where fuel economy is a primary design constraint, the dual function of the coolant as both a thermal protector and cycle enhancer is a compelling argument for regenerative cooling adoption.

A critical material constraint bounds all of these geometric considerations. GRCop-42, a copper-chrome-niobium alloy developed by NASA Glenn Research Center specifically for high heat-flux regenerative cooling applications, has a thermal conductivity of 320-380 W/mK and an operational temperature limit of 1073 K, above which creep and structural degradation become significant concerns (Gradl et al. 2019). Gândara et al. (2025) independently confirmed this limit in a thermal analysis of a small rocket engine using a validated one-dimensional numerical model, finding that even with a GRCop wall thermal conductivity of 350 W/mK, the inner wall temperature exceeded 1,073 K at the throat under a maximum heat flux of 18 MW/m² at 30 bar chamber pressure. This finding is directly relevant to the present study, which operates at 100 bar and similarly uses GRCop-42 as the structural material.

Despite this body of work on individual channel geometries and material limits, a gap remains in comparative feasibility studies that systematically evaluate how varying channel geometry affects wall temperature and coolant flow requirements under realistic hypersonic heat loads. Most existing studies address individual geometries in isolation and focus on rocket-engine conditions, with limited work on the scalability of these findings to the weight-sensitive, fuel-budget-constrained environment of a hypersonic aircraft engine.

Research Question

To what extent does cooling channel geometry, represented by varying convective heat transfer coefficients and coolant reference temperatures, affect the thermal feasibility of regenerative cooling for hypersonic propulsion structures?

Hypotheses

Null hypothesis (H_0): Varying the convective heat transfer coefficient and coolant reference temperature across the tested range will produce no significant difference in maximum wall temperature compared to the uncooled baseline.

Alternative hypothesis (H_0): Increasing the convective heat transfer coefficient and decreasing coolant reference temperature will produce a measurable and progressive reduction in maximum wall temperature, though wall temperatures may not fall below the GRCop-42 operational limit of 1073 K under the tested conditions.

Key Definitions

Conjugate Heat Transfer (CHT): A computational approach that simultaneously solves heat conduction in a solid domain and convective heat transfer in a fluid domain, capturing the coupled thermal interaction at their shared interface.

Convective heat transfer coefficient (h): A scalar value (W/m²K) representing the rate of heat transfer between a solid surface and an adjacent fluid per unit area per unit temperature difference. In this study, h is used as a proxy for channel geometry, with higher values representing enhanced configurations such as ribbed or finned channels (Gibreel et al., 2025).

GRCop-42: A copper-chrome-niobium alloy developed by NASA Glenn Research Center for high-heat-flux structural applications, characterised by a thermal conductivity of approximately 320 W/mK and an operational temperature limit of 1,073 K (Gradl et al., 2019).

Robin boundary condition: A mixed boundary condition applied to a wall surface, expressing convective heat transfer through the relationship q = h × (T_wall - T_ref), where T_ref represents the coolant reference temperature.

MATERIALS AND METHODS

Study Design

This study employs a computational simulation approach using steady-state Conjugate Heat Transfer (CHT) modeling to investigate the effect of cooling channel geometry on wall temperature distribution in a regeneratively cooled rocket nozzle operating under hypersonic thermal loads. The nozzle serves as a proxy for a high-heat-flux hypersonic propulsion component, consistent with the approach used in feasibility studies (Gândara et al., 2025). A controlled parametric design was used in which the convective heat transfer coefficient (h) and coolant reference temperature (T_ref) were systematically varied across ten simulation cases while all other boundary conditions, geometry, and material properties were held constant. The independent variable is cooling channel geometry, represented by h and T_ref. The dependent variable is maximum wall temperature in the solid domain measured in K. Case 1 serves as the uncooled baseline control, with all remaining cases representing actively cooled configurations.

Materials and Instruments

Simulation Platform

All simulations were conducted using SimScale, a cloud-based finite volume method (FVM) platform built on OpenFOAM v2406. The CHT V2 solver was used, which simultaneously resolves heat conduction in the solid domain and convective heat transfer in the fluid domain across their shared interface. The k-omega SST turbulence model was selected as it is the industry standard for wall-bounded heat transfer predictions in high-temperature flow applications.

Geometry

A converging-diverging rocket nozzle geometry was used, sourced from an open-access CAD repository and imported as a STEP file. The geometry consists of two domains: a solid shell representing the nozzle wall, and an internal fluid domain representing the combustion gas flow path extracted via SimScale's flow volume extraction tool and imprinted onto the solid to ensure mathematical heat transfer coupling at the interface. The nozzle inlet diameter is 0.06 m. No physical cooling channels were modelled in the geometry; instead, the coolant effect was applied directly as a boundary condition on the outer wall surface, consistent with the Robin BC simplification used in the literature (Ulas & Boysan, 2013).

Material Properties - Solid Domain

The nozzle wall material was assigned the properties of GRCop-42, a NASA-developed copper-chrome-niobium alloy for high-heat-flux applications (Gradl et al., 2019):

Property	Value
Thermal conductivity (k)	320 W/mK
Density (ρ)	8,920 kg/m³
Specific heat (Cp)	390 J/kgK
Operational temperature limit	1,073 K

Table 1: *GRCop-42 material properties assigned to the solid nozzle wall domain, including thermal conductivity, density, specific heat capacity, and the operational temperature limit above which creep degradation becomes significant (Gradl et al., 2019).*

Material Properties - Fluid Domain

The combustion gas was modelled as a custom incompressible fluid with thermodynamic properties derived from NASA Chemical Equilibrium with Applications (CEA) software for a LOX/methane combustion event:

Property	Value
Molar mass (M)	21.291 kg/kmol
Specific heat (Cp)	2,180 J/kgK
Dynamic viscosity (μ)	8.5×10^{-5} Pa·s
Thermal conductivity (κ)	0.27 W/mK
Laminar Prandtl number	0.69

Table 2: *Thermodynamic properties of the combustion gas used in the fluid domain, derived from NASA CEA software for a LOX/methane combustion event at 100 bar chamber pressure.*

Liquid methane was selected as the coolant for this study primarily due to its compatibility with LOX/methane propulsion cycles and its availability as both fuel and coolant in a single fluid system. As noted by industry practitioners, coolant selection in rocket propulsion is driven primarily by propulsive performance and cost considerations rather than thermal properties alone, since any cryogenic propellant will be sufficiently cold relative to combustion temperatures to drive meaningful heat transfer to the metal wall (Victor H., personal communication, 2026).

Variables

Independent Variables:

- Convective heat transfer coefficient h (W/m²K): 0 (adiabatic), 5,000, 10,000, 15,000, 25,000, 35,000, 50,000, 80,000
- Coolant reference temperature T_ref (K): 112, 130, 150

Dependent Variables:

- Maximum wall temperature in solid domain (K)
- Average wall temperature in the solid domain (K)
- Maximum convective wall heat flux on inner wall surface (W/m²)
- Total heat extraction rate Q (W), calculated as Q = h × A × (T_avg − T_ref)

Controlled Variables:

- Nozzle geometry
- Inlet pressure: 100 bar
- Inlet temperature: 3,500 K
- Outlet pressure: 0 Pa gauge
- Solid material properties
- Fluid material properties
- Turbulence model
- Mesh configuration
- Solver relaxation factors

Procedure

Case	h (W/m²K)	T_ref (K)	Group
1	0 (adiabatic)	n/a	1
2	5,000	112	2
3	15,000	112	2
4	25,000	112	2
5	50,000	112	2
6	25,000	130	3
7	25,000	150	3
8	15,000	112	4
9	35,000	112	4
10	80,000	112	4

Table 3: *Summary of simulation cases showing the convective heat transfer coefficient (h) and coolant reference temperature (T_ref) assigned to each case, with group membership. Case 1 is the uncooled adiabatic baseline. Cases belonging to multiple groups share boundary conditions with both parametric sweeps.*

Boundary Conditions

The following boundary conditions were applied across all ten cases:

Boundary Condition	Type	Value
Inlet (chamber face)	Pressure inlet	100 bar, 3,500 K
Outlet (nozzle exit)	Pressure outlet	0 Pa gauge, 300 K backflow
Outer shell (Case 1)	Adiabatic	Zero heat flux
Outer shell (Cases 2–10)	Robin BC (convective heat flux)	h and T_ref per case

Table 4: *Boundary conditions applied to all ten simulation cases, specifying inlet, outlet, and outer shell thermal conditions. Cases 2–10 replace the adiabatic outer shell condition with a Robin boundary condition defined by h and T_ref.*

The Robin boundary condition applies the relationship q = h × (T_wall − T_ref), where h represents the proxy cooling channel geometry and T_ref represents the coolant inlet temperature. Table 3 summarises the specific h and T_ref values assigned to each case.

Initial Conditions

To prevent solver divergence at startup, the fluid domain was pre-initialised at inlet pressure (100 bar) and temperature (3,500 K) with zero velocity. Pre-initialising at the inlet pressure and temperature eliminates the pressure and thermal discontinuities at iteration 1 that would otherwise cause negative density errors in the solver. The velocity was initialised at −3,500 m/s in the direction of flow to seed the solver with a physically directed flow field, ensuring the incompressible pressure-velocity coupling algorithm converged toward the correct flow direction from the first iteration rather than developing spurious recirculation from a zero-velocity start.

Solver Settings

All simulations used steady-state iteration with the following numerical settings applied consistently across all ten cases:

Parameter	Value
End time (iterations)	1000
Delta T (s)	10
Write interval	100
Relaxation factors (all fields)	0.15-0.3
Non-orthogonal correctors	3
Solvers	PBiCGStab for U, T, K, ω - GAMG for P
Gravity	Disabled

Table 5: *Numerical solver settings used consistently across all ten simulation cases, including iteration count, relaxation factors, non-orthogonal correctors, and solver algorithms.*

Relaxation factors were set conservatively between 0.15 and 0.3 across all fields to ensure numerical stability given the high inlet temperature and pressure conditions. Lower relaxation factors force the solver to take smaller incremental steps toward equilibrium per iteration, reducing the risk of divergence when large thermal and pressure gradients are present. Non-orthogonal correctors were set to 3 to improve pressure equation accuracy across mesh faces that are not perfectly perpendicular to the flow direction, which is unavoidable in curved nozzle geometry. Gravity was explicitly disabled throughout all simulations. Preliminary runs with gravity enabled were found to activate the p_rgh hydrostatic pressure formulation, which computes pressure as the difference between absolute pressure and a density-dependent hydrostatic head. At the extreme temperatures and densities present in this simulation, this term introduced large numerical errors that compounded each iteration and caused divergence, consistent with known OpenFOAM behaviour for high-temperature flows where gravitational effects are physically negligible compared to inertial and pressure forces.

Mesh Configuration

The computational mesh was generated using SimScale's automatic hex-dominant mesher. Mesh refinement was applied at 7, and boundary layer inflation was applied on all wall surfaces using 3 layers with an expansion ratio of 1.5 to resolve the near-wall thermal boundary layer where convective heat transfer occurs. The same mesh was used across all ten simulation cases to ensure that any differences in results are attributable solely to the boundary condition changes rather than mesh variation.

Post-Processing

After each simulation reached quasi-steady state, the following quantities were extracted from SimScale's post-processing environment using the surface statistics tool:

- Maximum wall temperature of the solid domain (K) - extracted via surface statistics on all solid wall faces
- Average wall temperature of the solid domain (K) - extracted via surface statistics on all solid wall faces
- Maximum convective wall heat flux on the fluid-solid interface (W/m²) - extracted via field statistics on the inner wall surface
- Average convective wall heat flux on the fluid-solid interface (W/m²) - extracted via field statistics on the inner wall surface
- Total heat extraction rate Q (W) - calculated post-simulation using Q = h × A × (T_avg − T_ref), where A is the outer wall surface area determined from the SimScale geometry panel

All temperature values were recorded from the solid domain only, as the research question concerns structural wall temperatures rather than bulk fluid temperatures.

Ethics

This study involves no human or animal participants. All data is computational and generated entirely by the author using the SimScale simulation platform.

Validation

No direct experimental validation was conducted in this study, which is acknowledged as a limitation in the Evaluation section. However, an informal consistency check was performed by comparing the measured maximum convective wall heat flux values against established literature ranges. The simulated maximum convective heat flux values of 56-88 MW/m² across cases are broadly consistent with the validated range of 0.8–80 MW/m² reported for liquid rocket engine combustion chambers by Huzel and Huang (1971), with values toward the upper end of this range expected given the high chamber pressure of 100 bar used in this study. Additionally, Gândara et al. (2025) reported a maximum throat heat flux of 18 MW/m² for a validated one-dimensional thermal analysis at 30 bar - the higher values obtained in the present study at 100 bar are physically consistent with the known pressure dependence of convective heat flux in rocket nozzles.

Analysis Plan

Results were analysed descriptively across four groups. Group 1 (Case 1) serves as the uncooled adiabatic baseline. Group 2 (Cases 2–5) isolates the effect of h by varying it from 5,000 to 50,000 W/m²K at constant T_ref = 112 K. Group 3 (Cases 4, 6, 7) isolates the effect of T_ref by varying it from 112 to 150 K at constant h = 25,000 W/m²K. Group 4 (Cases 8–10) represents a channel geometry proxy sweep, increasing h from 15,000 to 80,000 W/m²K at constant T_ref = 112 K, with each value corresponding to a literature-informed channel type: smooth rectangular (h ≈ 15,000 W/m²K, consistent with the range reported by Ulas and Boysan, 2013), cylindrical ribbed (h ≈ 35,000 W/m²K, interpolated from the enhancement factors reported by Gibreel et al., 2025), and fully finned (h ≈ 80,000 W/m²K, representing the upper bound of thermal performance factors reported by Gibreel et al., 2025).

For each case, the following quantities were recorded: maximum wall temperature (K), average wall temperature (K), maximum convective wall heat flux at the inner wall surface (MW/m²). Total heat extraction rate Q (W) was calculated post-simulation using Q = h × A × (T_avg − T_ref), where A is the outer wall surface area of 0.076 m², determined from the SimScale geometry panel face area measurement. This value was held constant across all ten cases as the same nozzle geometry was used throughout.

Thermal feasibility was assessed by comparing maximum wall temperature in each case against three material operational limits: GRCop-42 (1,073 K), Inconel 718 (approximately 1,200 K), and titanium alloy Ti-6Al-4V (approximately 600 K). A case was classified as thermally feasible for a given material only if its maximum wall temperature fell below that material's operational limit.

Trends in wall temperature reduction were examined within each group to determine whether increasing h or decreasing T_ref produced progressive reductions, and whether diminishing returns were observed at higher cooling intensities. The null hypothesis was evaluated by comparing the full range of maximum wall temperatures across cooled cases against the uncooled baseline; any measurable and consistent reduction constitutes grounds for rejection.

No inferential statistical tests were applied, as the study involves deterministic simulation outputs from a single mesh and solver configuration rather than sampled experimental data with associated measurement uncertainty.

RESULTS

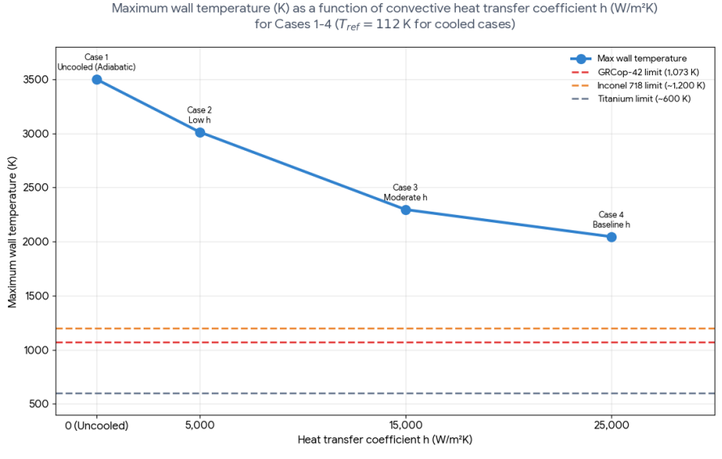

Figure 1: *Maximum wall temperature (K) as a function of convective heat transfer coefficient h (W/m²K) for Cases 1–4, with T_ref held constant at 112 K for all cooled cases. Case 1 represents the uncooled adiabatic baseline (h = 0). Case 5 is omitted from this graph. Dashed horizontal lines indicate the operational temperature limits of GRCop-42 (1,073 K), Inconel 718 (~1,200 K), and titanium alloy (~600 K). All cases remain above all three material limits, with diminishing returns in wall temperature reduction observed at higher h values.*

Baseline Case - Group 1

Case 1 is the uncooled adiabatic baseline, which produced a maximum wall temperature of 3,500 K and an average wall temperature of 3,488 K across the solid domain. These values exceed the GRCop-42 operational limit of 1,073 K by 2,427 K, the Inconel 718 limit of 1,200 K by 2,300 K, and the titanium alloy limit of approximately 600 K by 2,900 K. The maximum convective wall heat flux recorded at the inner wall surface was 56.55 MW/m², with an average of 0.545 MW/m² across the full nozzle surface. The null hypothesis cannot be evaluated from the baseline alone; however, it serves as the thermal reference against which all cooled cases are compared.

Group 2 - Effect of Heat Transfer Coefficient

Table 6 summarises the results for Cases 2–5., in which h was varied from 5,000 to 50,000 W/m²K at a constant T_ref of 112 K.

Case	h (W/m²K)	Max wall T (K)	Avg wall T (K)	Max heat flux (MW/m²)	Q total (W)
2	5,000	3,013	2,621	32.18	953,420
3	15,000	2,296	1,653	58.25	1,756,740
4	25,000	2,045	1,286	68.09	2,230,600
5	50,000	1,737	883	81.40	2,929,800

Table 6: *Group 2 results showing maximum wall temperature, average wall temperature, maximum convective wall heat flux, and total heat extraction rate for Cases 2–5, in which h was varied from 5,000 to 50,000 W/m²K at constant T_ref = 112 K.*

Across Group 2, maximum wall temperature decreased as h increased from 3,013 K at h = 5,000 W/m²K to 1,737 K at h = 50,000 W/m²K, a reduction of 1,276 K or 36.5% relative to the uncooled baseline. No case in Group 2 reduced the maximum wall temperature below the GRCop-42 operational limit of 1,073 K. The largest increment reduction occurred between Cases 2 and 3, where tripling h from 5,000 to 15,000 W/m²K produced a 717 K drop in maximum wall temperature. Diminishing returns were observed at higher h values: the increase from 25,000 to 50,000 W/m²K produced only a 308 K further reduction. Total heat extraction rate Q increased with h, reaching 2,929,800 W in Case 5. Maximum convective wall heat flux at the inner surface ranged from 32.18 to 81.40 MW/m² across Group 2, with no clear trend with h, suggesting that the hot-gas side heat load was consistent across cases and that h primarily affected how much of that load was extracted through the wall.

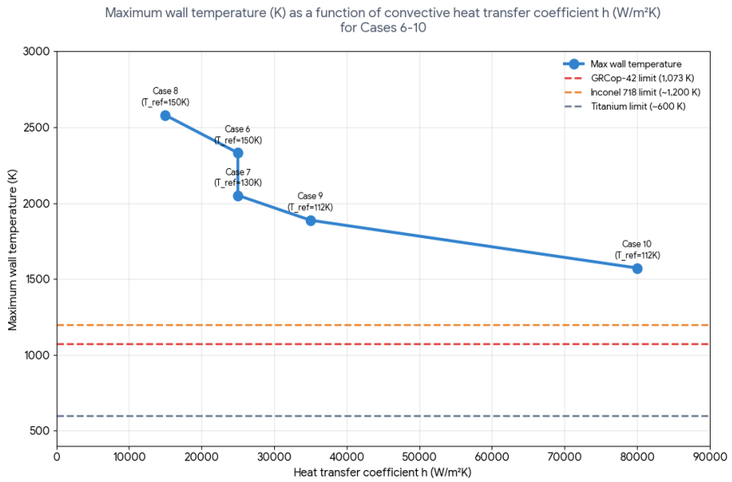

Figure 2: *Maximum wall temperature (K) as a function of convective heat transfer coefficient h (W/m²K) for Cases 6–10, spanning Groups 3 and 4. Data points are labelled with their respective coolant reference temperatures (T_ref). Cases 6 and 8 use T_ref = 150 K, Case 7 uses T_ref = 130 K, and Cases 9 and 10 use T_ref = 112 K. Dashed horizontal lines indicate the operational temperature limits of GRCop-42 (1,073 K), Inconel 718 (~1,200 K), and titanium alloy Ti-6Al-4V (~600 K). All cases remain above all three material limits, with diminishing returns visible at higher h values.*

Figure 2 shows maximum wall temperature as a function of h for Cases 6–10, combining data from Groups 3 and 4. Because these cases vary both h and T_ref, the curve represents the combined cooling parameter space rather than the isolated effect of a single variable; the individual effects of h and T_ref are reported separately in the Group 2 and Group 3 analyses above. Case 4 (h = 25,000 W/m²K, T_ref = 112 K), originally run as part of Group 2, is included here as the lower-bound T_ref comparison point.

Case	T_ref (K)	Max wall T (K)	Avg wall T (K)	Max heat flux (MW/m²)	Q total (W)
6	150	2,331	1,581	67.38	2,718,900
7	130	2,051	1,296	74.93	2,249,600
4	112	2,045	1,286	68.09	2,230,600

Table 7: *Group 3 results showing maximum wall temperature, average wall temperature, maximum convective wall heat flux, and total heat extraction rate for Cases 4, 6, and 7, in which T_ref was varied from 112 to 150 K at constant h = 25,000 W/m²K.*

Decreasing T_ref from 150 K to 112 K at constant h = 25,000 W/m²K produced a reduction in maximum wall temperature from 2,331 K to 2,045 K - a decrease of 286 K. The majority of this reduction occurred between T_ref = 150 K and T_ref = 130 K, with only a 6 K further reduction between 130 K and 112 K, indicating diminishing returns as T_ref approaches the cryogenic inlet temperature of liquid methane. Total heat extraction rate was highest in Case 6 despite the warmer coolant, which is consistent with the higher average wall temperature producing a larger driving temperature difference in the Robin BC formula. All three cases exceeded the GRCop-42 operational limit.

Group 4 - Channel Geometry Proxy

Cases 8, 9, and 10 systematically increased h from 15,000 to 80,000 W/m²K at constant T_ref = 112 K, representing smooth rectangular, cylindrical ribbed, and fully finned channel geometries, respectively.

Case	Geometry proxy	h (W/m²K)	Max wall T (K)	Avg wall T (K)	Max heat flux (MW/m²)	Q total (W)
8	Smooth rectangular	15,000	2,580	1,944	55.96	1,363,440
9	Cylindrical ribbed	35,000	1,887	1,073	74.93	2,556,260
10	Fully finned	80,000	1,572	688	88.49	2,188,800

Table 8: *Group 4 results showing maximum wall temperature, average wall temperature, maximum convective wall heat flux, and total heat extraction rate for Cases 8–10, representing smooth rectangular (h = 15,000 W/m²K), cylindrical ribbed (h = 35,000 W/m²K), and fully finned (h = 80,000 W/m²K) channel geometry proxies at constant T_ref = 112 K.*

Maximum wall temperature decreased from 2,580 K in the smooth rectangular configuration to 1,572 K in the fully finned configuration – a reduction of 1,008 K or 39.1% across the geometry group. Case 9 produced an average wall temperature of exactly 1,073 K, coinciding with the GRCop-42 operational limit, while Case 10 was the only simulation in the entire study to produce an average wall temperature of 688 K – below the operational limit, though the maximum wall temperature of 1,572 K remained above it. The fully finned channel configuration in Case 10 produced the highest maximum convective heat flux of any case in the study at 88.49 MW/m², consistent with reduced heat extraction through the wall, leaving more thermal energy concentrated at the gas-facing surface.

Summary Across All Cases

Across all ten cases, maximum wall temperature ranged from 1,572 K (Case 10, fully finned, h = 80,000 W/m²K, T_ref = 112 K) to 3,500 K (Case 1, uncooled). No case reduced maximum wall temperature below the GRCop-42 operational limit of 1,073 K, the Inconel 718 limit of 1,200 K, or the titanium alloy limit of 600 K.

DISCUSSION

Interpretation of Hypothesis

The null hypothesis, that varying the convective heat transfer coefficient and coolant reference temperature would produce no significant difference in maximum wall temperature, is fully rejected. A range of 1,928 K was observed between the uncooled baseline (Case 1, 3,500 K) and the most effective cooling configuration tested (Case 10, 1,572 K), representing a 55.1% reduction in maximum wall temperature relative to the adiabatic case. This magnitude of variation is unambiguous and confirms that the cooling channel geometry, represented by h and T_ref, exerts a strong and measurable influence on the wall thermal response.

The alternative hypothesis is fully supported. Increasing h and decreasing T_ref produced a progressive and monotonic reduction in maximum wall temperature across all tested groups. In Group 2, maximum wall temperature decreased from 3,013 K at h = 5,000 W/m²K to 1,737 K at h = 50,000 W/m²K — a reduction of 1,276 K achieved solely through increasing the convective heat transfer coefficient at constant coolant temperature. In Group 3, reducing T_ref from 150 K to 112 K at constant h = 25,000 W/m²K produced a further 286 K reduction, confirming that coolant inlet temperature contributes independently to cooling effectiveness. In Group 4, the geometry proxy sweep from smooth rectangular (h = 15,000 W/m²K) to fully finned (h = 80,000 W/m²K) produced the largest absolute temperature reduction of any group at 1,008 K. While no case reduced maximum wall temperature below the GRCop-42 operational limit of 1,073 K, the alternative hypothesis explicitly anticipated this outcome, and the progressive trend predicted was confirmed across all three groups.

Material Feasibility Analysis

The thermal context of this study is clarified by comparing simulated wall temperatures against the operational limits of structural materials relevant to hypersonic aircraft applications. Table 9 summarises these comparisons.

Material	Operational limit (K)	Coolest case max T (K)	Margin (K)
Titanium alloy (Ti-6Al-4V)	~600	1,572	-972
GRCop-42	1,073	1,572	-499
Inconel 718	~1,200	1,572	-372
10	80,000	112	4

Table 9: *Comparison of the best-case simulated maximum wall temperature (Case 10, 1,572 K) against the operational temperature limits of three aerospace structural materials: titanium alloy Ti-6Al-4V, GRCop-42, and Inconel 718. Negative margins indicate that the simulated temperature exceeds the material limit.*

No cooling configuration tested in this study produced maximum wall temperatures within the safe operating range of any of these three materials. The most extreme case is titanium alloy — used extensively in the SR-71 Blackbird airframe — whose operational limit of approximately 600 K was exceeded by the best-performing case by nearly 1,000 K. Even Inconel 718, the highest-temperature structural alloy considered, was exceeded by 372 K in the most aggressively cooled configuration. These findings suggest that regenerative cooling alone, without supplementary thermal protection such as film cooling or transpiration cooling, is insufficient to protect hypersonic aircraft structural materials under the combustion conditions modelled in this study. This conclusion is consistent with the assessment of an aerospace industry practitioner (Victor H., personal communication, 2026), who characterised the hypersonic thermal management problem as a cascade in which aerodynamic heating constrains material selection, which in turn necessitates active cooling systems that introduce operability and reusability complexity.

Comparison With Literature

The maximum convective wall heat flux values of 55.96–88.49 MW/m² measured across cases are consistent with the validated range of 0.8–80 MW/m² reported by Huzel and Huang (1971) for liquid rocket engine combustion chambers, with values toward the upper end of this range physically expected given the 100 bar chamber pressure used in this study. Gândara et al. (2025) reported a peak throat heat flux of 18 MW/m² for a one-dimensional thermal analysis at 30 bar using a GRCop copper alloy — the higher values obtained here at 100 bar are consistent with the known pressure dependence of convective heat flux in rocket nozzles. Gândara et al. (2025) further found that a GRCop-cooled engine exceeded the 1,073 K material limit at the throat even under more favourable conditions than those modelled in the present study, reinforcing the finding that regenerative cooling alone is insufficient under extreme heat loads.

The progressive reduction in wall temperature with increasing h observed in Groups 2 and 4 is consistent with findings from Gibreel et al. (2025), who demonstrated that fully finned channel configurations improve thermal performance factor by 25.37% over smooth baselines in hydrogen-cooled rocket engines. The diminishing returns observed between Cases 4 and 5 in Group 2 — where doubling h from 25,000 to 50,000 W/m²K produced only a 308 K reduction compared to the 717 K reduction achieved between Cases 2 and 3 — aligns with the general trend noted by Ulas and Boysan (2013), who found that increasing geometric enhancement yields progressively smaller marginal thermal improvements. The thermal recycling concept described by Jeon and Park (2024), in which coolant outlet enthalpy is fed back into the combustion cycle, suggests a pathway to improve the overall efficiency of the cooling architecture even when wall temperature targets cannot be met by geometry alone.

KISS Principle and Engineering Complexity

The geometric progression tested in Group 4 — from smooth rectangular to cylindrical ribbed to fully finned channels — reflects the engineering design principle that complexity should only be introduced when it solves a problem that cannot be addressed more simply (Victor H., personal communication, 2026). The results of this study confirm that this progression is justified: smooth channels (Case 8) failed to provide meaningful thermal protection, producing a maximum wall temperature of 2,580 K, while the fully finned configuration (Case 10) achieved the lowest maximum wall temperature in the study at 1,572 K — a 39.1% reduction within Group 4 alone. The data therefore supports the use of enhanced channel geometries in high-heat-flux applications, provided that the associated pressure drop penalties — which were not quantified in this study — remain within acceptable bounds.

Aircraft-Level Coolant Feasibility

The adaptation of regenerative cooling from rocket engines to hypersonic aircraft structures presents challenges that extend beyond thermal performance alone. As noted by an aerospace industry practitioner, the primary barriers are operability, reusability, and system complexity rather than raw cooling capacity. In a closed-cycle propulsion architecture where the coolant is also the fuel, the thermal energy absorbed during cooling is carried into the combustion chamber as preheated propellant rather than being lost from the propulsion budget — the performance penalty manifests as a modest reduction in specific impulse rather than additional fuel consumption. The more significant constraint identified by this study is that no tested configuration brought maximum wall temperatures within the safe operating range of practical hypersonic aircraft structural materials, suggesting that supplementary cooling methods such as film cooling or transpiration cooling would be required alongside regenerative cooling in any realistic aircraft application.

CONCLUSION

Cooling channel geometry, represented by the convective heat transfer coefficient and coolant reference temperature, exerts a strong and measurable influence on wall temperature in regeneratively cooled hypersonic propulsion structures. Maximum wall temperature decreased by 1,928 K (55.1%) between the uncooled baseline and the most effective cooling configuration tested, fully rejecting the null hypothesis. The alternative hypothesis was fully supported: increasing h and decreasing T_ref produced progressive, monotonic reductions in maximum wall temperature across all tested groups, with the geometry proxy sweep (Group 4) producing the largest single-group reduction of 1,008 K.

However, no configuration tested in this study reduced maximum wall temperature below the GRCop-42 operational limit of 1,073 K, nor below the operational limits of Inconel 718 (1,200 K) or titanium alloy (600 K). This finding carries a direct implication for hypersonic vehicle design: regenerative cooling alone, even with aggressively enhanced channel geometries, is insufficient to protect structural materials under the combustion conditions modelled (100 bar, 3,500 K). Supplementary thermal protection strategies, such as film cooling, transpiration cooling, or thermal barrier coatings, would be required alongside regenerative cooling in any realistic hypersonic aircraft application. Future work should extend this parametric approach to include combined cooling architectures and experimentally validated channel pressure drop data to assess the full system-level trade space.

EVALUATION

Strengths

The primary strength of this study is its controlled parametric design. By holding all geometry, material properties, mesh configuration, and solver settings constant across ten cases and varying only h and T_ref, the study isolates the effect of cooling channel geometry on wall temperature with high internal validity. The use of a single mesh across all cases eliminates mesh-dependent variation as a confounding factor. The Robin boundary condition approach, while a simplification, is consistent with established methods in the literature (Ulas & Boysan, 2013) and enables systematic comparison across a wide range of cooling intensities without the computational cost of resolving full conjugate coolant flow in physical channels. The simulated heat flux values of 55.96–88.49 MW/m² are broadly consistent with the validated range reported by Huzel and Huang (1971) and with the pressure-scaled results of Gândara et al. (2025), providing confidence that the thermal environment modelled is physically reasonable.

Limitations

Five limitations affect the reliability and generalisability of these findings, listed here in approximate order of significance.

First, the use of an incompressible fluid model for the combustion gas is the most significant physical simplification in this study. The simulation models flow through a converging-diverging nozzle, a geometry specifically designed to accelerate gas to supersonic velocities through the throat. Supersonic flow in a diverging section is a fundamentally compressible phenomenon: density changes drive the acceleration, and the pressure and temperature distributions through the throat are governed by compressible gas dynamics. An incompressible solver cannot capture these effects. This means the velocity field, pressure distribution, and consequently the convective heat transfer coefficient on the inner wall surface in the throat region (where thermal loads peak) are physically unreliable. The heat flux values reported in this study (56–88 MW/m²) fall within the range reported in the literature for high-pressure rocket engines, but this agreement may be coincidental rather than validating, since the underlying flow physics are not correctly resolved. Any future extension of this work should use a compressible flow solver with an appropriate equation of state to capture the real gas behaviour through the nozzle.

Second, no direct experimental validation was conducted. All results are derived from computational simulation, and no physical test data were collected to confirm the predicted wall temperatures or heat flux distributions. While the informal consistency check against published heat flux ranges provides some confidence, it does not constitute formal validation, and the absolute accuracy of the predicted temperatures cannot be confirmed without comparison to measured data from a physical nozzle under equivalent conditions.

Third, the Robin boundary condition simplification, while methodologically justified, does not capture the spatial variation in coolant temperature and heat transfer coefficient that would occur in a physical cooling channel. In a real regenerative cooling system, the coolant heats up progressively as it flows through the channel, meaning both

h and T_ref vary along the channel length. The uniform boundary condition used here represents an idealised scenario in which the coolant maintains constant properties along the entire wall surface. This likely underestimates maximum wall temperatures at the coolant outlet end of the channel, where the coolant is warmest and the local driving temperature difference is smallest. The results therefore represent a best-case thermal performance estimate for each h and T_ref combination.

Fourth, the pressure drop across the cooling channels was not quantified. In practice, the enhanced channel geometries that produce the highest h values — ribbed and finned configurations — also impose the greatest flow resistance, requiring larger and heavier coolant pumps. For aircraft applications where weight and power budgets are tightly constrained, pressure drop is a critical feasibility parameter. Without pressure drop data, the full system-level feasibility of the most effective configurations identified in this study cannot be assessed, and the practical advantage of high-h geometries may be overstated.

Fifth, the nozzle geometry used was sourced from an open-access CAD repository rather than designed to match a specific engine. While this is acceptable for a parametric feasibility study, the absolute temperature and heat flux values are geometry-dependent — nozzle contraction ratio, throat radius of curvature, and wall thickness all affect the thermal response. The results should therefore be interpreted as indicative of trends rather than as precise predictions for any particular engine design.

Improvements and Future Research

The most impactful improvement would be to replace the incompressible fluid model with a compressible flow solver coupled with a real-fluid equation of state, which would correctly resolve the supersonic flow through the throat and produce physically reliable pressure, velocity, and heat flux distributions in the region where thermal loads are most severe. Second, replacing the Robin boundary condition with a fully resolved coolant domain, which would model the physical methane flow through discrete cooling channels using a two-fluid CHT approach, would capture the spatial variation in coolant temperature and local heat transfer coefficient along the channel length, providing more realistic wall temperature predictions at the coolant outlet where thermal margins are tightest. Third, experimental validation could be pursued using a subscale copper nozzle section instrumented with thermocouples at known axial and circumferential positions, tested under controlled heat flux conditions using an oxy-methane torch or resistive heater. Comparing measured wall temperatures against simulation predictions for the same geometry and boundary conditions would establish the quantitative accuracy of the computational model. Finally, a system-level trade study incorporating coolant pressure drop, pump mass, and fuel budget constraints would allow the thermal performance gains demonstrated in this study to be weighed against the practical engineering costs of enhanced channel geometries in a hypersonic aircraft context.

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To what extent does interacting with cats affect the heart rate and blood pressure of individuals facing a stressful task?

ABSTRACT

The purpose of pursuing this research question is to determine whether there were significant scientific findings of benefits from regular physical interaction with domestic cats, particularly in our stress responses. For the study, 20 participants were selected and were separated into their respective age groups, 10 in each. Within each age group, 5 were randomly selected to be the control group and the remaining 5 for the experimental group. Prior to the experiment, all participants were taken to measure their initial heart rate and blood pressure. Afterwards the control group was directly taken to the "stressor" stage of the experiment where they were asked to read out a passage given to them to the entire group, participants took turns doing so. For the experimental group, after measurements were taken, they were allocated 30 minutes of play/relaxation time with cats at a cat cafe. Afterwards, they too underwent the same stressor of public speaking. Both groups had their post-activity heart rate and blood pressure within 20 minutes after undergoing the stressor. A two-way ANOVA test was chosen to analyze the data, essentially comparing the mean change in values of blood pressure and heart rate within both age groups and the control group and the experimental group. The findings supported the alternative hypothesis, showing that the experimental group showcased significantly smaller increases in heart rate and blood pressure in comparison to the control group after undergoing the stressor. These findings matter as it shows how animal companions are not just cute, furry animals but they also play an incredibly important role in regulating anxiety and stress for their human companions, suggesting that feline interaction is an effective pre-emptive tool for managing anxiety and provides a strong foundation to advocate for the popularization and integration of animal-assisted therapy as a standard practice within the Vietnamese healthcare industry.

Keywords

- **Animal-Assisted Therapy:** A therapeutic intervention that incorporates animals, such as cats, into a treatment plan to improve a patient's social, emotional, or cognitive functioning.
- **Two-Way ANOVA Test:** A statistical test used to determine the effect of two different nominal predictor variables (age group and treatment type) on a continuous outcome variable (blood pressure/heart rate).
- **Stressor Task:** A controlled activity designed to induce a stress response in participants, used here to measure the effectiveness of a prior intervention.

INTRODUCTION

Animal companionship has been shown to become more popularized as the world has become more modern. In this day and age, articles show that people prefer less invasive forms of therapy/treatment over one that is filled with medication, leading to there being a heavier focus placed upon research about the effects of animal companionship on human psychology and physiology. One common form of therapy that is actively prescribed in Western medicine is Animal-Assisted Therapy, which is an approach that supports a patient's mental health through the use of animal interaction. In Vietnam's modern medicinal landscape, this approach towards mental health treatment has not yet been popularized. Cardiovascular disease continues to be one of the leading causes of mortality in Vietnam, making up to approximately 33% to 39.5% of all annual deaths in the country (Viet Nam News). With more research being done to determine whether animals can act as a deterrent against acute stress can help raise awareness to encourage Vietnamese practitioners to incorporate therapeutic animals into their practices.

Many researchers have consistently tried to investigate the science behind Human-Animal Interaction, often coming to a conclusion that the common presence of animals can help lower the baseline cortisol levels of individuals. A popular and commonly cited study in 1995 conducted by Erika Friedmann and Sue A. Thomas discovered that heart attack survivors that owned pets at home were more likely to still be alive one year later compared to survivors who did not have pets, with only 6% of pet owners dying the following year compared to an alarming 28% of non-pet owners. More importantly, they also proved that animal companionship provided a certain level of support that existed independently of other factors such as wealth, age, disease severity, showing that pets provided a unique health benefit that was not achievable by receiving medicinal treatment and having friends. Friedmann's study along with several other studies conducted by Odendaal, Meintjes, Allen, Blascovich, & Mendes all found a direct negative correlation between pet interaction and stress levels measured through cortisol and blood pressure. However, it is worth noting that the majority of these previous studies placed a heavier emphasis on canine interaction but not for feline interaction. Therefore, this study focuses specifically on feline interaction rather than canine interaction to address the research gap.

My **research question** is "To what extent does interacting with cats affect the heart rate and blood pressure of individuals facing a stressful task?"

My **null hypothesis** (H_0) is: there is no significant difference in the mean change of heart rate and blood pressure between the experimental group (cat interaction) and the control group following a stressor task; and **alternative hypothesis** is: participants who engage in feline interaction will exhibit significantly lower mean increases in heart rate and blood pressure compared to the control group following a stressor task.

Key definitions

- **Human-Animal Interaction:** The broad field of study investigating the mutual bond and shared influences between people and animals, encompassing both psychological and physiological exchanges.
- **Cortisol:** A steroid hormone produced by the adrenal glands, often referred to as the "stress hormone," which increases in the bloodstream during "fight or flight" situations.
- **Null Hypothesis (H_0):** Assumption that there is no relationship, no effect, or no difference between the groups you are testing.
- **Alternative Hypothesis (H_a):** What you expect to happen. It states that there is a relationship or a significant difference between your groups.

METHODOLOGY

Study Design

I conducted an experiment for this study and utilized a control group and an experimental group and compared the outcomes from each group. I replicated the same experiment in two separate times for two different age groups, one for a younger aged group and the other for an older aged group. For the experimental group, I changed the procedure by exposing them to cats 30 minutes prior to them undergoing a stressor, as compared to the control group where participants were immediately exposed to the stressor after initial measurements were taken. After the experiment, both control and experimental groups had their final post-stressor measurements taken no more than 20 minutes after the stressor occurred.

Participants / Sample

The sample was obtained through convenience sampling within the local neighbourhoods of Phu My Hung to ensure their participation in the cat cafe activity. The total final sample size was n=20 human participants. Two separate trials were conducted for two age groups to test whether age (a potential confounding variable) affected stress response. Group A (Younger) consisted of participants from the ages of 13 to 19, and Group B (Older) consisted of participants from the ages of 42 to 59. Participants were randomly assigned to either the control or experimental group, with 5 in each. There were no data removals made for this experiment.

Materials/Instruments

To measure the blood pressure and heart rate, a standard Digital Sphygmomanometer was used. I choose to use this device as it is commonly used in clinical settings and is trusted for its ability to accurately measure results. Another material I used was the "stressor" text paragraph, which was a 500-word paragraph on topics related to various Economic topics. I used AI tools to help standardize the difficulty level of each text as well as write out these texts for me to help with time efficiency. Lastly, I used a stopwatch on my phone to help time exactly 30 minutes to ensure strict compliance with my experiment and also used the watch again to make sure all post-stressor measurements were taken no more than 20 minutes after the stressor to maintain its validity.

Variables

My two independent variables were the cat or no cat treatment. This was the only thing I changed in my experiment, the experimental group received 30 minutes of cat interaction whereas the control group did not. My dependent variables were blood pressure (systolic and diastolic) and heart rate. However, for my analysis I used the difference between the 2 instances when the measurements were taken, as this would measure how extremely or minimally their measurements spiked caused by the stressor. My controlled variables were the stressor (which I kept constant for both control and experimental groups), the environment in which I recorded the initial measurements in, the time in which I made to sure to take the post-stressor measurements in (within 20 mins after the stressor), and the equipment I used to measure the blood pressure and heart rate. Two confounding variables warrant attention: individual differences in public speaking anxiety, which may produce larger physiological spikes independent of cat interaction; and individual cat preference, which may limit the relaxation benefit for participants who dislike cats.

Procedure

The experiment was carried out within a two week time period, with each experiment occurring each week (one for the younger group, one for the older group). The experiment and data collection occurred in Ho Chi Minh City. For the first period of the experiment, all 10 participants were guided into a quiet cafe where they could be seated, they were instructed to take off their shoes and simply relax for the next 15 minutes. After this, participants were randomly assigned using a random number generator to either the control group or experimental group and were promptly separated into their respective groups. At this point for each group, I had their baseline data measured and recorded with the help of my parents and the data was inputted into the document under Control 1, Control 2, Exp 1, Exp 2. Measurements of systolic and diastolic blood pressure were taken along with heart rate using a digital sphygmomanometer. Two separate sphygmomanometers were used, 1 for each group, however the brand and type of sphygmomanometer was kept consistent. Following this, the experimental group were then instructed to go relax with cats at a cat cafe upstairs, specifically to engage in activities such as petting the cats or feeding them treats and not to run or fall asleep with the cats. Meanwhile, the control group remained within the quiet space and were instructed to sit in a circle. Each participant in the control group was given a sheet of paper containing a 500 word passage. In any order, the participants took turns reading their passage out loud while standing. For the experimental group, the same stressor process was repeated. After each group has completed the stressor, they are led back by the moderator to get their post-stressor measurements taken, using the same sphygmomanometer used for the same group earlier. The experiment is then concluded.

Ethics

As participants were determined based on volunteer sampling through filling out a form sent out to the neighbourhood community, ensuring that all participants were willing to participate in the experiment and had an interest in the study's goals. Additionally, participants were also informed of their ability to withdraw from the experiment at any time and also that their physiological measurements were kept entirely anonymous. For data collection, each participant was assigned a unique code such as (EA, EB, EC or CA, CB, CC..etc) and only mean differences of the entire group were used to compare in the study so no singular participant's physiological data can be identified. Only the main researcher, the moderators, and the project supervisor had access to the data and such data will be deleted immediately after the research paper is published as well. Finally, animal welfare is guaranteed as participants had to abide by the rules and regulations of the cat cafe which prohibited abusive treatment of the cats.

Statistical / Analysis Plan

I used a Two-Way ANOVA test because I have multiple independent variables and want to see if there are relationships when the two variables; the test allows me to determine whether cat interaction produced a significant difference, and the test allows me to determine whether age played a role in the outcome of the difference in measurements (ex. Did the older group have overall larger blood pressure differences compared to the younger group?).

To use the test, I have to first determine whether my data follows a normal distribution or if it's skewed. A skewed data set might result in an inaccurate output given by the ANOVA test. Secondly, I must check whether the scattering of the data points are roughly equal for all four data sets (Young+Exp , Young+Ctrl , Old+Exp , Old+Ctrl). Thirdly, I can assume that there is independence in the results (as there was random assignment) and that one participant's heart rate had no effect on another participant's.

One person's resting heart rate/blood pressure can drastically differ from another person's. To control this, I calculated a mean difference value for each participant using the formula: Value = Post-stressor measurements - Initial measurements, and inputted these values into my ANOVA test. I defined statistical significance as $p < 0.05$.

RESULTS

Group	Condition	Mean HR (bpm) +/- SD	Mean PSHR (bpm) +/- SD	Mean BP (mmHg)	Mean PSBP (mmHg)	ΔHR (bpm)	ΔBP (mmHg)
Young	Exp	73 ± 3.4	80 ± 4.1	118.60/77.2	127.2/81.4	+7 ± 1.2	SBP: +8.6 ± 2.1 DBP: +4.2 ± 1.4
Young	Ctrl	74.4 ± 3.8	111 ± 6.2	120/78.6	145.6/91	+36.60 ± 5.4	SBP: +26.6 ± 4.8 DBP: +12.4 ± 3.2
Old	Exp	76.8 ± 4.2	84.8 ± 5.0	129.2/84.2	139.6/89.2	+8 ± 1.8	SBP: +10.4 ± 2.5 DBP: +5 ± 1.6
Old	Ctrl	78 ± 4.5	117.6 ± 7.3	130/85	161.4/99.8	+39.6 ± 6.1	SBP: +31.4 ± 5.2 DBP: +14.8 ± 3.9

Test used: Two-way ANOVA was used to assess the effectiveness of the Treatment (Cats vs. No Cats) and Age (Young vs. Old) regarding stress reactivity.

Degrees of Freedom: df = (1, 16) for all effects, where the numerator df = 1 (treatment levels – 1) and denominator df = 16 (total n – number of groups = 20 – 4).

Variable	Effect	F-statistic	p-value	Decision
Heart Rate	Treatment	583.4	< 0.001	*Reject H_0*
	Age	2.49	0.134	Fail to reject H_0
	Interaction	0.62	0.441	Fail to reject H_0
Systolic BP	Treatment	298.35	< 0.001	*Reject H_0*
	Age	11.93	0.003	*Reject H_0*
	Interaction	3.31	0.088	Fail to reject H_0
Diastolic BP	Treatment	385.71	< 0.001	*Reject H_0*
	Age	12.19	0.003	*Reject H_0*
	Interaction	3.05	0.100	Fail to reject H_0

DISCUSSION

As the "treatment" aspect across all three aspects returned a p-value that is lower than 0.005, the null hypothesis was rejected, indicating that cat interaction does have a significant effect on reducing the physiological impacts of stress. The experimental group experienced significantly smaller increases in heart rate and blood pressure post-stressor compared to the control group (all Treatment effects, $p < 0.001$).

One apparent trend shown in the data is that across both age groups, cat interaction reduced physiological spikes substantially in comparison to the control group. This is evident in the F-statistics for treatment in heart rate and blood pressure. As they range from 298.55 to 583.4, the high numbers indicate that they are located on the extremely far tail of the data curve which means that there is an extremely small chance the results occurred due to chance alone. Overall, the results suggest that cat interaction has a significant effect in calming our physiological reactions regardless of age.

The research findings particularly align with Edward Wilson's study in 1984 about Biophilia Hypothesis, which suggests that humans are "healthier" when they are connected to nature and other living things as they positively influence aspects such as stress, creativity and concentration. Additionally, the results directly aligned with the findings of Karen Allen's study regarding cardiovascular reactivity and pet presences, which found that "relative to people without pets, people with pets had significantly lower heart rate and blood pressure levels during a resting baseline, significantly smaller increases (ie, reactivity) from baseline levels during the mental arithmetic and cold pressor, and faster recovery."

Practically, these results point towards a positive future. It suggests that it would be very easy to apply the same "animal therapy" programs across various age groups without specifications having to be made to accommodate older or younger patients.

CONCLUSION

The results of the study shows that interacting with cats does have an effect on the heart rate and blood pressure of individuals when facing a stressful task. My alternative hypothesis that participants who engage in feline interaction will exhibit significantly lower mean increases in heart rate and blood pressure compared to the control group following a stressor task was strongly supported by the findings. The ANOVA test consistently demonstrated a significant difference between the results of the experimental group compared to the control group with all p-values falling below 0.001, well below the $\alpha = 0.05$ threshold.

The study's findings matter as it directly showcases how cat interaction can completely be used as a non-pharmaceutical intervention to help patients manage acute stress. The benefits that the study highlights encourages future incorporation of pet-therapy in work places, campuses, or medical facilities to better support cardiovascular health of individuals across Ho Chi Minh City of all age groups. Additionally, as the study shows the positive impacts pet-interaction has on older participants, this could suggest future implementation of pets in nursing homes and senior centers with the purpose of assisting with stress/emotional management.

Strengths

One of the things I believe was well carried out in my experiment was maintaining a controlled experiment for the study. I was strict in making sure that data was inputted in time before the effects of the experiment would be out and ensuring that all equipment used was kept consistent to prevent faulty equipment from affecting my data thus compromising the study as a whole. I also made sure to standardize steps in my experiment to control for confounding variables. Additionally, I adhered to ethical guidelines such as getting consent from all participants, making sure participants are safe throughout the entire process, and ensuring the safety and well treatment of the animals involved in the study.

Limitations

One limitation of the study was the small sample size which limits the generalizability of the results. Additionally, participants were selected based on their willingness to volunteer and also were sampled in specific neighbourhoods in Phu My Hung, both affecting the generalizability of the results as well. A larger sample size, selected across many neighbourhoods within Ho Chi Minh City would have allowed for easier generalizability and application of the study's results. The study also mainly focused on determining whether there was an effect rather than how long this effect could last for.

Improvements

To improve, I would increase the sample to n = 80 (n = 20 per condition across age groups: 10 young cat, 10 young control, 10 old cat, 10 old control) and target professionals whose day to day work life involves a high level of 'stress. I would also purchase monitors that the participants could wear for 24 hours after performing the stressor to gather a more in-depth answer to my research question and determine whether there is a sustaining effect from the interaction. Finally, I would also ensure that cats of similar temperaments were used throughout the experiment, as if not some participants may interact with a more playful cat while others interact with a calmer cat and these differing factors might interfere with the results.

In the future, there should be an increased focus amongst researchers in finding out the longevity of the effects of pet interaction, primarily answering questions such as "How long until the effects of a 30 minute interaction with cats were off?" and "Does longer interaction time with animals mean better protection against stress triggers or do individuals only need to meet a certain number of minutes of interaction to experience the same level of protection? If so, what is the number of minutes the individual needs to meet?"

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Does calcium carbonate concentration affect early-stage growth of mung beans in acidic soil?

ABSTRACT

This investigation examines the remediating effects of Calcium Carbonate ($CaCO_3$) on the physiological development of Vigna radiata (mung beans) cultivated in highly acidic soil. Soil acidity remains a primary agricultural constraint, particularly in tropical regions, where low pH induces aluminum toxicity and restricts the bioavailability of essential macronutrients. The study utilized a controlled experimental design with four treatment groups (n=10) categorized by lime concentration: 0g/kg (Control), 2g/kg, 5g/kg, and 10g/kg. Statistical analysis via a One-Way ANOVA revealed that soil treatment was the dominant factor in plant development, yielding an Eta-squared (η2) of 0.952. This indicates that 95.2% of the observed variance in growth was directly attributable to the lime concentration. The results followed a distinct unimodal trend, where vertical growth peaked at the 5g/kg dosage (mean height = 5.85cm) before significantly declining at the 10g/kg dosage (mean height = 4.11cm). With a $p<0.0001$ and a substantial Effect Size (f=4.45), the study provides evidence that precise $CaCO_3$ application is essential for maximizing crop yield in acidic substrates.

INTRODUCTION

Vietnam's agricultural background

Agriculture is a primary sector in Vietnam, being the main land usage in the Mekong Delta and Central Highlands and employing over 30% of the workforce (FAO, 2024). This industry is one of the country's main economic backbone as Vietnam is noted as a world market leader in products such as coffee, and rice. Large regions of Vietnam, especially the Mekong Delta, contain high levels of pyrite. When exposed to air via drainage or farming, this creates sulfuric acid, dropping soil pH below 4.0 (Minh, 2023). In these acidic Vietnamese soils, Aluminum (Al^{3+}) and Manganese (MN^{2+}) become soluble and toxic to plant roots (Panda et al., 2024), while essential nutrients like Phosphorus (P) become unavailable for crops to absorb. To solve this, Vietnamese farmers traditionally use compost, or agricultural lime to balance the acidity from the soil, but finding the precise dosage is critical for cost-effectiveness and crop health.

Relevance and significance

Mung beans *(Vigna radiata)* are a commonly grown crop in Vietnam, often grown in rotation with rice to restore soil fertility (University of California, 2025). They are incorporated, and a key player, in a large portion of the Vietnamese diet, and a staple export product. Mung beans are significantly more sensitive to low pH than other legumes due to its enzymes only working in its optimal pH range. In acidic soils, the abundance of H+ ions and soluble Aluminum (Al^{3+}) stunts root elongation, preventing the plant from accessing deep water and nutrients. Legumes like mung beans rely on Rhizobium bacteria to fix nitrogen from the air. This process involves converting nitrogen gas (N_2) into a form of nitrogen such as ammonia. This symbiotic relationship is highly pH-dependent; in soils with a pH below 5.5, nodulation is often inhibited (USDA, 2023), leading to nitrogen deficiency characterized by yellowing leaves (chlorosis). While Calcium Carbonate $(CaCO_3)$ is the standard treatment to raise pH, mung beans can also suffer from "over-liming." Excessive lime can lead to micronutrient deficiencies like Iron or Zinc (The Fertilizer Institute, 2024). Finding the specific "optimal" dosage is therefore a matter of economic survival for local farmers.

Research question & hypothesis

The research question: To what extent does the concentration of Calcium Carbonate ($CaCO_3$) affect the early-stage growth of Vigna radiata in acidic garden soil over a seven-day period?

Null Hypothesis: There will be no statistically significant difference in the growth metrics of the mung bean plants across different $CaCO_3$ treatment groups.

Alternative Hypothesis: Increasing $CaCO_3$ concentration will significantly improve plant growth and health up to the threshold predicted at 5g/kg, after which growth will plateau or decline due to its incompatibility with alkaline and, consequentially, nutrient lockout.

SCIENTIFIC BACKGROUND

Soil acidity in Vietnam's agricultural regions is defined by a high concentration of dissolved Hydrogen ions (H+) and the presence of CEC. In untreated acidic sulfate soils, these conditions create a toxic environment that limits nutrient availability and causes metal toxicity. The application of Calcium Carbonate ($CaCO_3$) initiates a multi-stage remediation process essential for the survival of Vigna radiata.

Chemical properties of $CaCO_3$

The primary function of $CaCO_3$ is the neutralization of acidity in the soil solution (Hockings, 2025). Upon contact with the moist soil, the carbonate anion (CO_3^{2-}) reacts with hydrogen ions, which are the chemical components that contributes to low pH levels, to form:

$$CaCO_3(s)+2H^+(aq) \rightarrow Ca^{2+}(aq)+H_2O(l)+CO_2(g)$$

As the concentration of H+ ions decreases, pH levels increase, creating a more hospitable environment for both its enzymatic activity and microbial symbiosis.

Another function of $CaCO_3$ is cation displacement. The soil's Cation Exchange Capacity (CEC) represents the total negative charges on the surface of clay minerals and organic matter (Smith, 2022), which are adsorption sites for positively charged ions. In highly acidic environments, these exchange sites mainly consist of Aluminum (Al^{3+}) and Manganese (MN^{3+}) cations.

When $CaCO_3$ is dissolved, the soil solution is flooded with Calcium ions (Ca2+), resulting in a displacement reaction. The Ca^{2+} ions displace the Al^{3+} and MN^{2+} from the soil's exchange complex into the soil solution. Since they became mobile, the chemicals are now available to react with the rising concentration of hydroxyl groups (OH^-) created by the agricultural lime. This allows them to undergo hydrolysis, turning it into a solid, harmless mineral.

Without this displacement, the aluminum cations would remain adsorbed to the soil. This would effectively buffer the soil against pH changes, preventing the lime from permanently neutralizing the environment. Furthermore, the formation of aluminum hydroxide makes the metal no longer able to penetrate the plasma membrane of the mung bean's root cells and cell walls, which allows the soil's acidity to be remediated without the need to physically extract the metal.

While neutralizing acidity is beneficial, exceeding a pH of 7.5 can create secondary stress. In alkaline conditions, micronutrients such as Iron (Fe) become insoluble and precipitate out of reach. This leads to Iron Chlorosis, and the plant cannot produce sufficient chlorophyll, resulting in yellowing leaves with green veins.

Bean sprouts physiology

During post germination, bean sprouts transition from using seed energy (cotyledons) to acquiring nutrients through its primary taproot. This biological process is controlled by two factors: root structural integrity and the chemical solubility of essential minerals.

When Vietnamese soils in agricultural regions are acidic, Aluminum (Al^{3+}) becomes highly soluble and acts as a potent phytotoxin. It binds to the pectins within the cell walls of the root, making it rigid and physically preventing cell elongation (Marschner, 2023).

Consequently, the roots become thick and lack the fine root hairs required for water absorption. By applying $CaCO_3$ to raise the pH, these toxic Al^{3+} ions are precipitated out of the soil solution, protecting the meristem (contains plant tissue for stem cells) and allowing the taproot to establish the plant's foundation.

EXPERIMENT

Procedure

1. Four identical pots were filled with a standardized volume of acidic soil. The specific mass of $CaCO_3$ was measured using a digital scale and mixed into the soil for each treatment group.
2. The soil was left to sit for 48 hours to allow the lime to react with the ions.
   +1
3. Ten mung bean sprouts were planted in each pot at a depth of 2cm, equally spaced.
4. The same volume (50mL) of distilled water, adjusted to a neutral pH of 7, was applied daily to ensure consis
   tent moisture and prevent untreated tap water minerals from affecting soil chemistry.
   +1
5. Height (cm) and leaf count were recorded daily from the soil level.

Variables

Variable Type	Variable Name	Explanation
Independent	Concentration of $CaCO_3$	The mass of calcium carbonate added to the soil (0g, 2g, 5g, 10g per kg of soil)
Dependent	Plant growth metrics	Vertical height (cm) and total leaf count of each sprout.
Controlled	Environmental and biological factors	Sunlight exposure, temperature, and volume of neutral water (50mL/day Seed type (Vigna radiata), planting depth (2cm), and soil type (pH 5.0 baseline)

Materials used include: 40 mung bean seeds, 4.0 kg of acidic garden soil (baseline of pH 5), agricultural lime, planting pots.

Measuring tools used include: digital gram scale, metric ruler, electronic pH meter, measuring cup

Experimentation results

Group	Target Lime (g/kg)	Measured pH (Day 0)	Measured pH (Day 7)
A	0g	5.2	5.1
B	2g	5.9	6.0
C	5g	6.7	6.8
D	10g	7.8	7.9

Table 1: *Soil pH from Day 1 to Day 7 across treatment groups*

Treatment Group	Mean Height (cm)	Mean Final Biomass (g)	Observed Health Status
A (0g - Control)	3.22	0.12	Stunted, Chlorotic (Yellowing)
B (2g - Low)	4.54	0.21	Moderate growth, Light green
C (5g - Optimal)	5.85	0.35	Robust, Dark green, Strong stems
D (10g - High)	4.11	0.24	Slightly stunted, Tip-burn

Table 2: *Mean plant growth (measured in height and biomass) on Day 7*

Group A - Control (pH 5.2)

Plant ID	Height (cm)	Initial Biomass (g)	Final Biomass (g)
A1	3.4	0.08	0.13
A2	3.1	0.07	0.11
A3	3.5	0.09	0.14
A4	2.9	0.07	0.10
A5	3.3	0.08	0.12
A6	3.0	0.08	0.11
A7	3.2	0.09	0.13
A8	3.6	0.08	0.15
A9	2.8	0.07	0.09
A10	3.4	0.08	0.12

Table 3: *Plant growth of Group A from Day 1 to Day 7*

Group B - Low (pH 5.9)

Plant ID	Height (cm)	Initial Biomass (g)	Final Biomass (g)
B1	4.6	0.08	0.22
B2	4.3	0.09	0.20
B3	4.8	0.09	0.24
B4	4.4	0.08	0.19
B5	4.7	0.09	0.23
B6	4.2	0.08	0.18
B7	4.5	0.09	0.21
B8	4.9	0.08	0.25
B9	4.4	0.07	0.19
B10	4.6	0.08	0.20

Table 4: *Plant growth of Group B from Day 1 to Day 7*

Group C - Medium (pH 6.7)

Plant ID	Height (cm)	Initial Biomass (g)	Final Biomass (g)
C1	5.9	0.09	0.36
C2	6.1	0.08	0.38
C3	5.7	0.09	0.34
C4	6.0	0.08	0.37
C5	5.8	0.08	0.35
C6	5.6	0.09	0.33
C7	5.9	0.07	0.36
C8	6.2	0.09	0.39
C9	5.5	0.07	0.32
C10	5.8	0.09	0.35

Table 5: Plant growth of Group C from Day 1 to Day 7

Group D - High (pH 7.8)

Plant ID	Height (cm)	Initial Biomass (g)	Final Biomass (g)
D1	4.2	0.09	0.25
D2	3.9	0.06	0.22
D3	4.3	0.08	0.26
D4	4.1	0.09	0.24
D5	4.0	0.09	0.23
D6	3.8	0.07	0.21
D7	4.4	0.08	0.27
D8	4.2	0.09	0.25
D9	4.0	0.07	0.23
D10	4.2	0.09	0.25

Table 6: *Plant growth of Group D from Day 1 to Day 7*

DATA ANALYSIS

Graphical representation

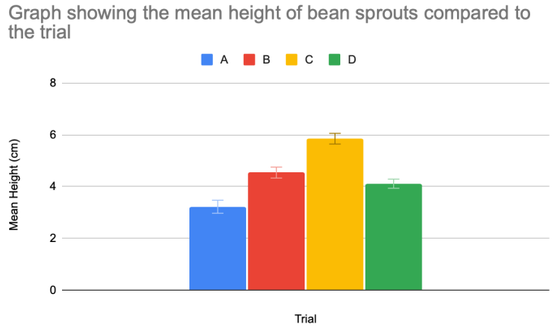

Figure 1: *Mean height by treatment*

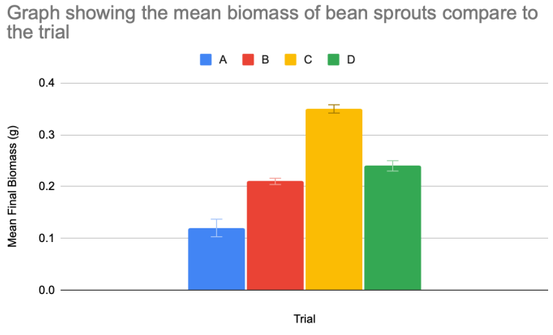

Figure 2: *Mean biomass by treatment*

Statistical analysis

To determine if the observed variations in *Vigna radiata* biomass were due to the CaCO3 treatments or random environmental fluctuations, a One-Way Analysis of Variance (ANOVA) was conducted at a significance level of α=0.05.

Hypothesis Testing and P-Value: The null hypothesis predicted that there would be no significant difference in mean biomass across the four treatment groups (n=10 per group). When the ANOVA was performed, the results yielded a statistically significant effect, $F(3,36)=238.00, p<0.0001$. Since this p-value was significantly lower than the alpha level, the null hypothesis was rejected. This indicated that the differences between the sample averages were statistically significant and not the result of sampling error.

Effect Size and Variance ($\eta 2$): The magnitude of the experimental impact was further assessed using the Effect Size (f) and Eta-squared ($\eta 2$):

- **Effect Size (f=4.45):** The calculated effect size of 4.45 was categorized as large, indicating a substantial physical difference in growth between the groups.
- **Variance Explained ($\eta 2$=0.952):** The $\eta 2$ value showed that the concentration of CaCO3 explained 95.2% of the total variance in plant biomass. This high percentage suggested that the experimental design successfully controlled for external variables, leaving the soil chemistry as the dominant factor in plant development.

Post-Hoc Analysis (Tukey HSD): Following the rejection of the null hypothesis, a Tukey HSD post-hoc test was conducted to identify which specific pairs of groups differed significantly. The test revealed that Group C (5g/kg) was significantly different from both the control group (0g/kg) and the over-limed Group D (10g/kg) at the $p<0.01$ level. While the difference between the control and Group B (2g/kg) was significant, the comparison between Group C and all other groups confirmed that the 5g/kg dosage provided the most substantial physiological benefit. This precise comparison validated the unimodal trend, showing exactly where the optimal dosage lies before the "over-liming" effect begins to diminish growth.

Evaluation

The first indicator of data reliability is the behavior of the Standard Deviation (s) across the four treatment groups. When plotted as error bars, there is no overlap between all the groups, and this suggests that the mean growth in Group B, C and D are distinct and not a result of random noise. Furthermore, the standard deviation values remained consistently low (ranging from 0.006 to 0.017 for the biomass trial and ranging from 0.176 to 0.252 for the height trial), indicating a common trend and increasing data reliability. The data also shows a clear unimodal trend, where growth increases steadily from 0g/kg to 5g/kg before declining at the 10g/kg concentration. This trend is highly consistent with the research which suggested that the initial rise represents the neutralization of toxic aluminum ions *(Al^{3+})*, while the subsequent drop in Group D reflects the "over-liming" effect, where excessive alkalinity begins to inhibit the plants' abilities to absorb the nutrients.

The main source of random error is likely genetic variability within the Vigna radiata seeds. Despite selecting those with similar physical traits, individual seeds may possess different metabolic efficiencies, leading to slight height discrepancies that are independent of soil pH. Furthermore, although all pots were kept in the same location, uncontrollable differences such as varying airflow or shadows cast by angle may have caused unequal treatment to the plants. Another potential source of error revolves around soil heterogeneity. The method of mixing *$CaCO_3$* does not ensure that each individual seed is exposed to the same amount of lime, meaning some plants may have been growing in different pH levels. While these errors are minimized through the repetition of seeds for each group, it does not get rid of the uncertainty within the experiment.

CONCLUSION

The aim of this research was to determine the optimal concentration of Calcium Carbonate *($CaCO_3$)* required to remediate soil acidity and maximize the growth of *Vigna radiata*. By comparing four distinct dosage levels, this study has successfully identified the optimal range of which will best support the neutralization of acidic soil.

The experimental data portrayed a quadratic relationship between *$CaCO_3$* application and plant height. The control group experienced a stunted growth averaging 3.22cm likely due to aluminum toxicity and limited nutrient bioavailability. However, the introduction of lime as a neutralizing agent showed significant increase in the plants' survivability. Furthermore, through different statistical measurements, such as the standard deviation error bars for these two groups, the results provide visual and statistical certainty that this growth was a direct result of the soil treatment.

Importantly, the study also demonstrated the over-liming effect. In Group D (10g/kg), both plant biomass and vertical growth significantly declined compared to the previous trials. This suggests that while *$CaCO_3$* is essential for neutralizing H+ ions, an excess concentration creates an alkaline environment that hinders the uptake of phosphorus and essential micronutrients.

In the real-world agricultural context, these findings demonstrate that soil remediation is not a "more is better" process. To maximize the physiological health of *Vigna radiata* in acidic regions, a precise application of 5g/kg is recommended. This dosage provides the optimal chemical equilibrium necessary to reduce the stress caused by low pH levels and ensure efficiency and effectiveness is maximized when growing crops.

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How do teenagers who primarily use cashless payments and teenagers who primarily use physical cash compare in terms of spending behavior?

ABSTRACT

Digital payments spending online and in-person has surged worldwide in the past decade, increasing from $1.7 trillion in 2014 to $18.7 trillion in 2024 and projected to exceed $33.5 trillion by 2030("10 Years of Cash, Cards and Crypto"). With technology such as digital wallets and BNPL continuously emerging to make transactions feel more convenient, this study investigates how cashless payments psychologically influence teenagers' spending habits compared to cash. A quantitative cross-sectional survey was implemented with teenagers and young adults through convenience sampling. Participants recorded their transactions throughout 1 week, including their medium of transaction and the amount transacted. The statistical analysis included descriptive statistics, Welch's t-test, and a Mann-Whitney U-test. The dataset (n=29) was positively skewed with outliers, emphasizing the median values. The t-test found no significant difference in mean spending (p=0.325). However, the Mann-Whitney U-test showed a significant difference in spending distributions (p=0.008). Cashless payments had a substantially higher median (600,000 VND) compared to cash payments (99,999 VND). Although cashless payments do not differ much in terms of the mean, both the medians and the Mann-Whitney U-test indicated that cashless payments are associated with higher spending. The results support the "Pain of paying" theory that suggests individuals who use cashless transactions show a reduced amount of psychological restraint to money and are more willing to spend money.

INTRODUCTION

Cashless Adoption

Previous research has focused on the aspects that affect consumers' acceptance of cashless payment methods. For example, in a study conducted by Tanha and colleagues, it was noted that consumption values such as functional value, epistemic value, and conditional value significantly affect individuals' willingness to accept cashless payment methods(Tanha et al.). Cashless readiness is a measure of individuals' preparedness to use cashless payment methods. This measure is affected by individuals' familiarity with technology and their trust in electronic transactions (Balakrishnan and Gan). Furthermore, cashless readiness is a crucial factor in determining whether consumers fully shift from cash-based payment methods to cashless payment methods (Balakrishnan and Gan). As consumers become comfortable with cashless payment methods, their consumption behaviors may change. The ease and comfort associated with digital payment methods may help eliminate the psychological constraints associated with spending money. Hence, it becomes imperative for an individual to understand the factors associated with the adoption of cashless payment methods while understanding their influence on consumer spending behavior.

The growing trend of using cashless payments has significant implications in terms of its effect on consumer behavior in relation to consumption. Compared to traditional cash payments, digital payments like credit cards and mobile wallets are less salient in terms of money usage. Brown, Nacht, Nellen, and Stix (2023), in a working paper published by the Swiss National Bank, examine the relationship between consumer behavior in relation to consumption and the usage of cashless payments. The study provides empirical results that show a significant impact of cashless payments on consumer behavior in relation to consumption. The study found that an increase in the use of cashless payments leads to an increase in consumer spending of **6.5%.** This effect is more apparent in consumers who are present-biased. **Present bias is a behavior where consumers are more inclined to consume in the present rather than in the future, or in simple terms, are impulsive.*

This phenomenon can be explained through the notion of the "pain of paying," which implies that making actual physical transactions using cash heightens one's psychological awareness of spending more than making digital transactions does. Cashless transactions, on the other hand, depersonalize the transaction process, making spending less "physical" and hence more psychologically reasonable. Therefore, consumers tend to engage in more impulsive spending if they use digital transactions. Moreover, this study found that consumers do not make use of cash as a self-regulatory strategy, implying that consumers' biases cannot be overcome even if they are aware of their spending habits.

Reduced Pain of Paying

- **Pain of Paying (Cash):** When an individual pays money for a service or a product using cash, they are com pelled to physically hand over the money in the form of notes and coins. This creates a sense of loss for the individual involved in the transaction.
- **Reduced Pain of Paying (Cashless):** When an individual uses cashless payment methods for transacting business, they do not feel the pain associated with paying for the service or the product they have purchased. This creates a sense of comfort for the individual involved in the transaction.

This is important in the context of a constantly changing financial environment, where digital payment systems are increasingly being used. As more and more consumers opt for the more convenient and efficient digital transactions instead of physical cash transactions, it becomes important to take note of their potential impact on consumer spending patterns. The current study is important as it attempts to build on existing literature by providing empirical evidence of how payment systems impact consumer spending patterns.

HYPOTHESIS

H1 (Spending): Consumers tend to spend more when using cashless payments in comparison to cash payments.

H2 (Impulsivity): Impulsive consumers will exhibit a higher tendency for higher purchases compared to consumers with lower impulsivity.

METHODOLOGY

Research Design

For this study, a quantitative approach in a cross-sectional survey design was used to examine the relationship between payment mode, specifically between cash and cashless transactions, and student spending behavior. This approach was deemed appropriate because it enables data collection in a numerical form that can be statistically analyzed to determine patterns, associations, and differences in data. This approach is particularly appropriate in studying student spending behavior because it enables an objective comparison of monetary amounts transacted in various modes of payment.

A cross-sectional design in a quantitative study entails collecting data at a single point in time rather than over a significant period of time. This design was considered appropriate because it is efficient and convenient, particularly in studying a behavior in a student population. Although a longitudinal study design can also be appropriate in studying behavior because it can reveal trends over a significant period of time, a cross-sectional study can offer a snapshot analysis of behavior in relation to a specific aspect, in this case, mode of payment behavior.

Participants

The participants were teenagers and young adults who voluntarily participated in the online survey. The sample in this study consisted of participants who were sampled using a convenience sampling approach. This approach mainly included distributing the online survey to peers and using online forums, communities, and threads to reach a large number of participants in a short period of time. However, since it may result in a sampling bias as participants were not sampled randomly, the study may not represent the larger population of teenagers as a whole.

The study did not obtain any identifiable information from the participants since it was entirely anonymous. In addition, it was entirely voluntary since participants had the option to withdraw from the study at any given time.

Data Collection

The data collection instrument used in this study was a structured survey that collected data in the form of individual transaction entries. It collected detailed data on participants' spending behavior in a systematic way and was made available online to ensure that participants were able to fill it in at their own convenience.

Each participant filled in data on their spending behavior in the following manner:

- Payment method (cash, debit card, credit card, digital wallet)
- Amount spent per transaction
- Merchant type (Food & Drink, Shopping, Transportation, Entertainment)
- Impulsiveness score (self-reported)
- Additional demographic and behavioral variables (e.g., card ownership, digital payment access)

Participants were asked to report their transactions as accurately as possible, either based on recent purchases or recall of typical spending behavior. The impulsiveness score was self-reported, using a 10-point Likert scale (10 being extremely impulsive), to capture the degree to which a purchase was planned or spontaneous and to add another factor that could explain the participants' spending behavior.

Cashless payments were defined as any non-cash method, including debit cards, credit cards, and digital wallets.

Variables

- **Independent Variable:**
  Payment method (categorized as cash or cashless).
- **Dependent Variable:**
  Amount spent per transaction. This variable is continuous and represents the monetary value of each recorded transaction, allowing for precise measurement and comparison. The currency used throughout is the Vietnamese Dong (VND). All foreign currency transactions were converted to VND.
- **Additional Variables:**
  Merchant type and impulsiveness score were included to explore secondary relationships and behavioral patterns.

Ethical Considerations

Ethical considerations were made in the entire process of carrying out the research. First, participation in the research was entirely voluntary, and participants were made aware of this before they participated in the survey. Participants were also allowed to stop participating in the research at any time they felt like. These measures were implemented to ensure that the research was conducted ethically, as expected in human-subject research.

All the data collected in this research was anonymous, and no personal information was collected from the participants. The data collected in this research were used for purely academic purposes and were not shared with any third party.

RESULTS

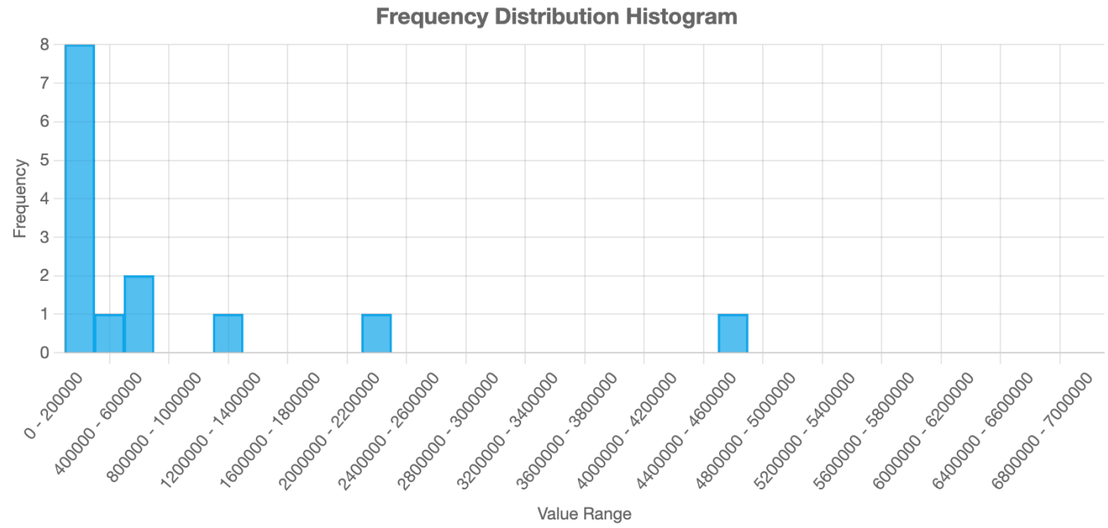

Figure 1: *Histogram - Cash Payments (VND)*

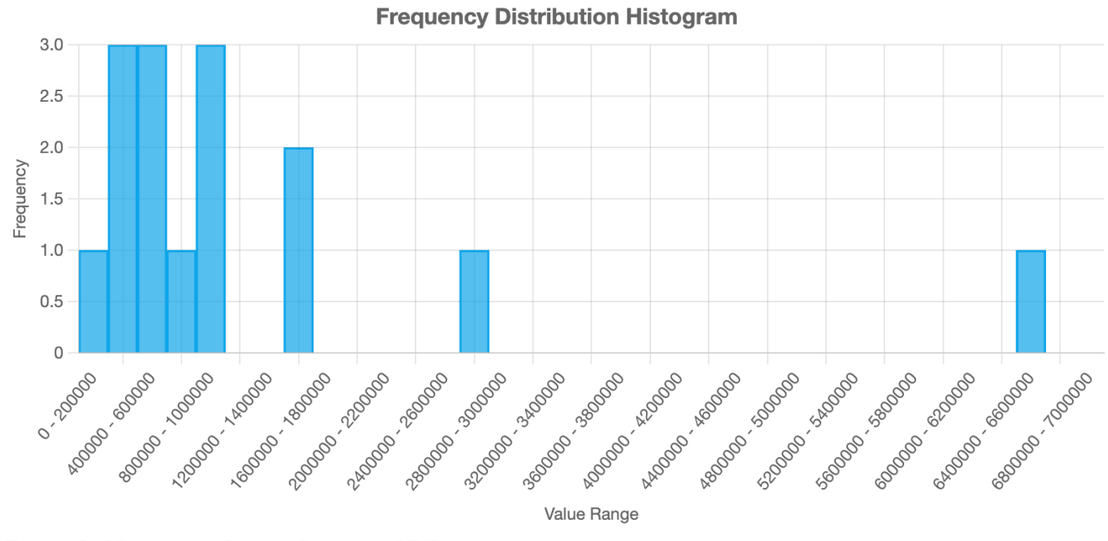

Figure 2: *Histogram - Cashless Payments (VND)*

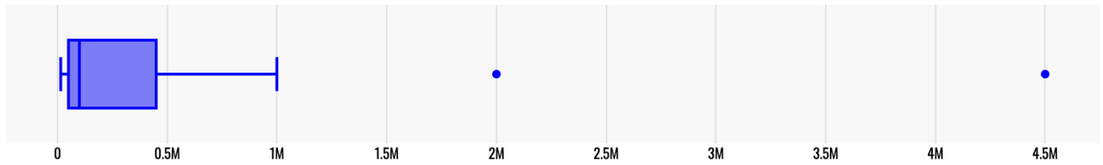

Figure 3: *Box Plot - Cashless Payments (VND)*

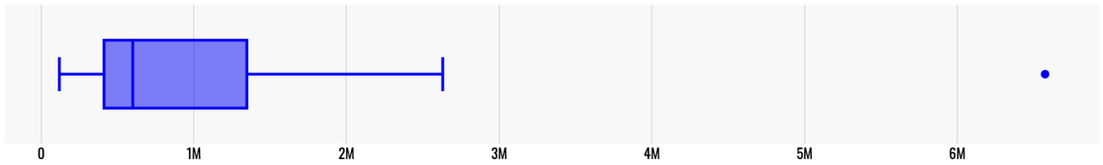

Figure 4: *Box Plot - Cashless Payments (VND)*

Descriptive Statistics

An analysis was conducted to compare spending amounts between cash and cashless payment methods. Table 1 summarizes the key descriptive statistics for both groups.

Payment Method	Sample Size (n)	Mean (VND)	Median (VND)	Standard Deviation
Cash	14	652,786	99,999	1,233,298.44
Cashless	15	1,187,599	600,000	1,624,634.96

Table 1: *Descriptive Statistics of Spending by Payment Method*

The mean for cashless transactions was significantly higher than for cash transactions (1,187,599 VND). Likewise, the median for cashless transactions was considerably higher than for cash transactions. This suggested an overall tendency for higher spending with cashless transactions.

On the other hand, the significant difference between the mean and median for the cash transactions indicated the existence of extreme values (outliers). This resulted in a positively skewed distribution for the cash transactions. In contrast, the small difference between the mean and median for the cashless transactions suggested a stable pattern for their transactions.

Independent Samples t-Test (Welch's t-test)

An independent samples t-test (Welch's t-test) was conducted to determine whether the difference in mean spending between cash and cashless payment methods was statistically significant.

$$t = (\bar{x}_1 - \bar{x}_2) / \sqrt{[(s_1^2 / n_1) + (s_2^2 / n_2)]}$$

Statistic	Value
t-value	1.00
p-value	0.325
Significance	Not significant (p > 0.05)

Table 2: *Welch's t-test Results*

The results showed that there was no significant difference in terms of spending between the two forms of payment. This can be supported by the fact that t(27) = 1.00, p = 0.325. This means that the null hypothesis, which states that there is no difference in spending between cash and cashless payments, cannot be rejected.

Distribution Characteristics

Both forms of payment methods have a positive skewness in their spending amount distributions. This implies that a higher number of transactions are within the low to moderate spending amount category, while a smaller number of transactions are in the higher spending amount category.

Regarding cash payments, it is evident that there is a large variation in spending amount values. This is due to the large gap between the mean and median values.

On the other hand, in the case of cashless payments, it is evident that there is a smaller gap between the mean and median values.

DATA ANALYSIS

This dataset contains 29 transactions: 14 cash payments and 15 cashless payments. The main pattern is that cashless payments are associated with higher spending, but the data are also strongly right-skewed, which means a few large transactions have a big effect on the averages.

Measure	Cash (n = 14)	Cashless (n = 15)
Mean amount (VND)	652,785.86	1,187,599.42
Median amount (VND)	99,999.00	600,000.00
Standard deviation	1,233,298.44	1,624,634.96
Minimum (VND)	15,000	120,000
Q1 (VND)	54,250	424,500
Q3 (VND)	437,500	1,195,000
IQR (VND)	383,250	770,500
Maximum (VND)	4,500,000	6,574,985.08
Skewness	2.76	2.98

Table 3: *Descriptive Statistics*

The median is relevant in this case, especially since it is not a symmetrical distribution. The median amount of money spent in cash mode was only 99,999 VND, whereas in cashless mode, it was 600,000 VND. This suggests that a "typical" transaction in cashless mode is much higher in value than in cash mode. The difference in means and medians in both cases suggests that there are outliers in this data set, especially at the higher end.

The cash group includes very large transactions, such as 2,000,000 VND and 4,500,000 VND, while the cashless group also includes very large transactions, including 2,629,994.03 VND and 6,574,985.08 VND. These extreme values inflate the mean, which is why the median gives a clearer picture of the real center of the data.

The independent samples t-test using Welch's correction found that there was no significant difference in mean spending, as $t(25.97) = 1.00$, $p = 0.325$. This indicates that, on average, there is no significant difference due to payment methods. Nevertheless, it is important to note that there is a need to consider the actual distribution of the data. The nature of the data revealed a significant positive skew, and outliers affect the reliability of using the mean as a reliable value and may have hindered the reliability of the t-test.

Mann-Whitney U Test

H_0: The distributions of spending are equal
H_1: Cashless spending is greater than cash spending

$$U = n_1n_2 + [n_1(n_1 + 1) / 2] - R_1$$

Statistic	Value
U-value	160.5
P-value (one-tailed)	0.008
Significance	Significant ($p < 0.05$), reject H_0

Table 4: *Mann–Whitney U Test Results*

However, due to the skewed nature of the data, a non-parametric test is very likely to be effective. A Mann-Whitney U test revealed a significant difference in the distributions, $U = 160.5$, $p = 0.008$ (one-tailed). This suggests that the spending patterns of cash and cashless are not the same. In fact, cashless transactions tend to be higher than cash transactions.

Interpretation

These results, taken together, imply that the statistical analysis has some bearing on the result. The results from the t-test imply that there is no significant difference in terms of means, while the Mann-Whitney test implies a significant difference in terms of overall distributions.

In relation to behavioral economics, the results obtained are consistent with the pain of paying concept. The pain of paying concept implies that transactions involving cash involve a tangible transfer of money, which might function as a psychological constraint. On the other hand, cashless transactions might be less tangible, thus encouraging individuals to spend more. The higher median obtained from the cashless transactions implies that individuals tend to spend a larger amount when using cashless transactions.

On the whole, the most conclusive result obtained from the study is that cashless transactions tend to be higher than cash transactions, particularly when observing the median values and the distribution. However, it is important to note that the extent of the difference depends heavily on the method of statistical analysis, because mean-based comparisons do not show a significant difference.

CONCLUSION

This study aims to determine how teenagers who primarily use cashless payment modes compare with those who primarily use physical cash in terms of their spending behavior. The results showed that there is no significant difference between the two groups in terms of their average spending. However, there is a significant difference between the two groups in their spending patterns.

This is supported by the results of the descriptive statistics and median analysis, showing that teenagers who primarily used cashless payment modes have a tendency to spend higher amounts compared to their counterparts who mostly used physical cash. The results of the Mann-Whitney U test also showed a significant difference between the two groups, with a significant difference in their spending behavior. The independent samples t-test did not show a significant difference between the two groups in their spending behavior. This is possibly because there are extreme values in the data, causing the data to be highly skewed.

The results showed that there is a significant difference between the two groups in their spending behavior.

From the behavioral point of view, the study's findings are also in line with the "pain of paying" theory, which implies that the use of cash leads to a greater mental awareness of the amount spent, which might otherwise act as a restraint on the amount spent. In this case, the cashless mode of payment might remove this restraint and hence increase the amount spent.

However, it should be noted that the study's findings could be affected by certain limitations, and the results should be taken with a certain amount of caution. Further research would be needed to validate the study's findings and extend the research.

In sum, it can be stated that there is no conclusive statistical proof to support hypothesis H1 since no statistically significant difference in the average expenditure among the two groups under consideration was found. Still, it can be said based on nonparametric tests and descriptive statistics that teenagers paying by cashless means tend to spend more than their peers making payments in cash. Therefore, the "pain of paying" effect is observed.

LIMITATIONS/EVALUATIONS

There are several strengths that can be seen in this research. The research focuses on a current problem that is becoming increasingly relevant, specifically how the type of payment method affects the spending habits of adolescents in today's cashless society. Secondly, the study employs a quantitative approach, providing an opportunity to numerically analyze the difference between two variables – namely, cash versus cashless payments. Thirdly, analyzing transaction data is more informative compared to surveying respondents' perceptions of their own spending habits. Finally, using both Welch's t-test and the Mann-Whitney U test helps look at the same dataset from both a mean-based perspective and a distribution-based perspective.

However, there are some flaws with the study. First, since the study uses cross-sectional analysis, it only provides an understanding of the behaviors of the respondents within a single period. The study, therefore, only establishes a correlation between the mode of payment and spending behavior and does not directly establish causation. Second, the data are self-reported by the respondents, who might have missed some expenses or might have misremembered them, thus decreasing the reliability of the findings. Third, the use of convenience sampling to obtain the sample may result in the lack of representation of the teenage population, which will limit the generalizability of the results.

In order to further improve the quality of the study, the future study could adopt a longitudinal design to allow the researcher to observe any changes in spending behavior over a period of time. Furthermore, increasing the size of the sample population and ensuring randomness in sampling would increase the level of generalizability. Additionally, instead of depending on subjective data such as self-reports for expenditure, a more objective approach involving transaction records would help ensure higher levels of validity and reliability.

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Investigating the Mechanics of Soft Robotic Actuators: Pressure vs. Performance

ABSTRACT

This study investigates how pneumatic pressure influences the bending angle and tip force of a soft robotic actuator, addressing the limited availability of experimental studies that quantitatively link pressure to both kinematic and kinetic performance. A PneuNet actuator fabricated from Dragon Skin 10 silicone was tested using a controlled experimental setup, where pressure was incrementally increased from 15 to 25 psi. At each pressure level, bending angle and tip force were recorded over three trials to improve reliability. A regression analysis was conducted to evaluate the relationship between pressure and actuator performance, using the coefficient of determination (R^2) and a significance threshold of $\alpha = 0.05$. The results showed a strong positive relationship between pressure and bending angle ($R^2 = 0.98$, $p < 0.001$) as well as tip force ($R^2 \approx 0.97$, $p < 0.001$). As pressure increased, bending angle rose significantly before gradually plateauing, while force output increased more rapidly at higher pressures. These findings demonstrate a non-linear transition from deformation-dominated behavior at low pressures to stiffness-dominated force generation at higher pressures. This confirms that pneumatic pressure is an effective and controllable parameter for tuning soft actuator performance. The results have important implications for the design of soft robotic systems, particularly in applications requiring a balance between precision and force.

INTRODUCTION

Soft robotics is a rapidly developing field of engineering that focuses on constructing machines from compliant materials such as silicone elastomers and flexible polymers rather than rigid metallic components (Soft Robotics Toolkit, 2024). This enables robots to safely interact with delicate and unpredictable environments, inspired by biological systems such as octopus tentacles and elephant trunks (Rus & Tolley, 2015). Consequently, soft robotic systems are increasingly being applied in areas such as minimally invasive surgery, rehabilitation, and agricultural automation.

Previous research has explored the behavior of pneumatic soft actuators using hyperelastic material models such as the Neo-Hookean and Mooney–Rivlin models, which describe the non-linear stress–strain response of silicone materials. Studies by Polygerinos et al. (2015) and Marchese et al. (2014) demonstrated that increasing internal pressure leads to significant deformation; however, these studies primarily focused on qualitative or kinematic analysis rather than quantitatively linking pressure to both motion and force output.

Pneumatic actuation using Pneumatic Networks (PneuNets) is one of the most common methods in soft robotics. These actuators exploit the hyperelastic properties of silicone to achieve large, reversible deformations under relatively low pressures. However, due to the inherent non-linear behavior of these materials, predicting actuator performance in terms of bending angle and force output remains complex.

This study addresses this gap by experimentally investigating the relationship between pneumatic pressure and both bending angle (kinematic output) and tip force (kinetic output) in a controlled environment.

Research Question:

How does the pneumatic pressure applied to a soft robotic actuator influence its resulting bending angle and tip force?

Hypotheses:

H_0 (Null Hypothesis): There is no significant relationship between pneumatic pressure and the bending angle or tip force of the actuator.

H_1 (Alternative Hypothesis): Pneumatic pressure has a significant positive effect on both the bending angle and tip force of the actuator.

THEORETICAL BACKGROUND

Design Principles and Embodied Intelligence

Soft robots utilize "Embodied Intelligence," where the mechanical properties of the material handle part of the control tasks (ResearchGate, 2022). By naturally deforming around objects, the robot reduces the computational load required for complex grasping.

PneuNet Mechanics and Hyperelasticity

A PneuNet actuator typically consists of a flexible top layer and a strain-limiting bottom layer. When pressurized, the chambers expand, but the stiff base resists elongation, forcing the actuator into a curve. Because silicone is **hyperelastic,** it does not follow a linear stress-strain path.

Engineers use complex models like the **Mooney–Rivlin** or **Neo-Hookean** models to predict how these materials stretch and deform under pressure (ScienceDirect, 2020).

Due to hyperelasticity, silicone materials exhibit a non-linear stress–strain relationship, meaning that deformation does not increase proportionally with applied force. This explains why actuator behavior changes across different pressure ranges.

METHODOLOGY

Step-by-Step Procedure

To ensure replicability, the experiment was conducted following these steps:

1. **Mounting:** Secure the silicone PneuNet actuator to a rigid vertical stand using a 3D-printed clamp.
2. **Calibration:** * Reset the digital protractor to 0° against the vertical axis of the stand. Digital protractor (±1°), force sensor (±0.01 N). Tare the high-precision force sensor to 0.00 N before each measurement.
3. **Pressure Connection:** Connect the regulated air compressor to the actuator inlet using 4mm pneumatic tubing, ensuring an airtight seal with a zip-tie.
4. **Incremental Testing:**
   - Increase pressure starting at 15 psi, moving in 1 psi increments up to 25 psi.
   - For each increment, allow the actuator to stabilize for 3 seconds.
5. **Data Collection:** Record the bending angle using the digital protractor and the tip force by allowing the actuator to press against the sensor at a fixed 5cm distance.
6. **Repetition:** Repeat the entire pressure sweep **three times (3 trials)** to calculate the mean and identify any outliers.

Safety and Ethical Considerations

- **Pressure Hazards:** Working with compressed air carries a risk of "bursting." The actuator was tested in a polycarbonate enclosure to protect the researcher from flying debris in the event of material failure.
- **System Limits:** The air compressor's regulator was locked at a maximum of 30 psi to prevent accidental over-pressurization.
- **Eye Protection:** Safety goggles were worn at all times during the inflation phases.

Variables

- **Independent Variable:** Pneumatic pressure (psi, 15–25 in 1 psi increments).
- **Dependent Variables:** Bending angle (°), tip force (N).
- **Controlled Variables:** Actuator geometry/material (Dragon Skin 10), ambient temperature (~22°C), fixed 5 cm sensor distance, 3-second stabilization.

Statistical Analysis Plan

A regression analysis was conducted to evaluate the relationship between pneumatic pressure and each dependent variable. The strength of the relationship was assessed using the coefficient of determination (R^2), with statistical significance evaluated at $\alpha = 0.05$. Residual analysis was used to verify model assumptions.

ANALYSIS AND DISCUSSION

Raw data and first look at the correlation

Pressure (psi)	Avg Bending Angle (°)	Avg Tip Force (N)
15	42	0.8
15	50	1.2
15	46	1
16	58	1.1
16	50	0.9
16	55	1
17	71	1.5
17	73	1.6
17	76	1.4
18	89	2
18	100	2.6
18	94	2.4
19	104	2.6
19	102	2.5
19	99	2.3
20	122	3.3
20	130	4
20	127	3.9
21	137	4.1
21	135	4.3
21	133	4.2
22	151	4.9
23	164	5.8
23	180	7
23	180	7
24	176	6.7
24	178	6.9
24	175	6.8
25	187	7.5
25	185	7.4
25	184	7.3

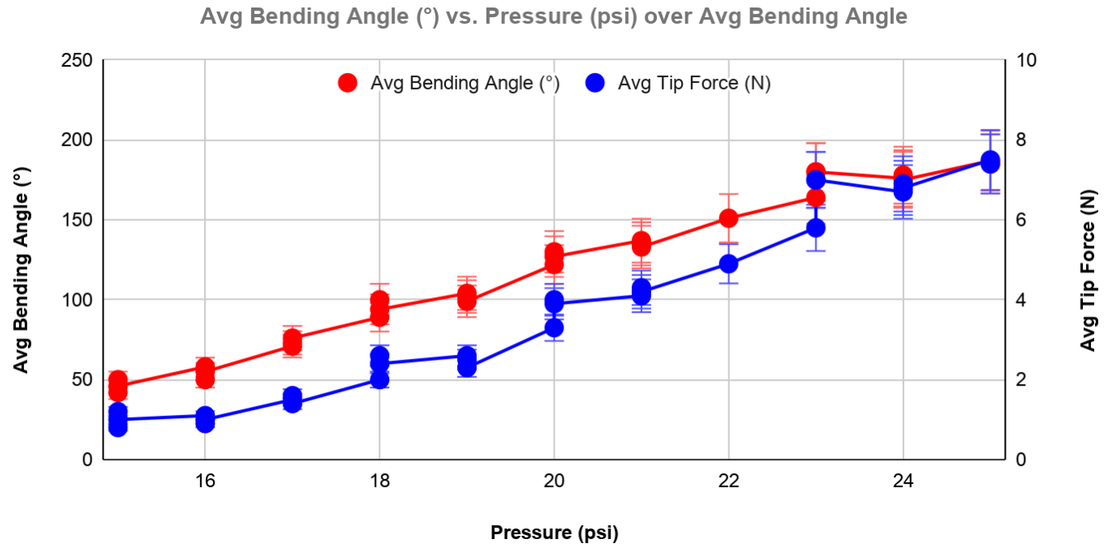

Figure 1: *Mean bending angle as a function of pneumatic pressure. Error bars represent ± 1 standard deviation.*

Statistical Rigor and Error Analysis

The data presented represents the mean (x) of three separate trials. To ensure reliability, the Standard Deviation (SD) was calculated for each pressure point. The resulting dual-axis graph (Figure 1) includes error bars; where error bars are small, it indicates high precision in the pneumatic system.

Pressure (psi)	Mean Bending Angle (°)	SD (Angle)	Mean Tip Force (N)	SD (Force)
15	46.00	4.00	1.00	0.20
16	54.33	4.05	1.00	0.10
17	73.33	2.52	1.50	0.10
18	94.33	5.50	2.33	0.31
19	101.67	2.52	2.47	0.15
20	126.33	4.05	3.73	0.38
21	135.00	2.00	4.20	0.10
23	174.67	9.24	6.60	0.69
24	176.33	1.53	6.80	0.10

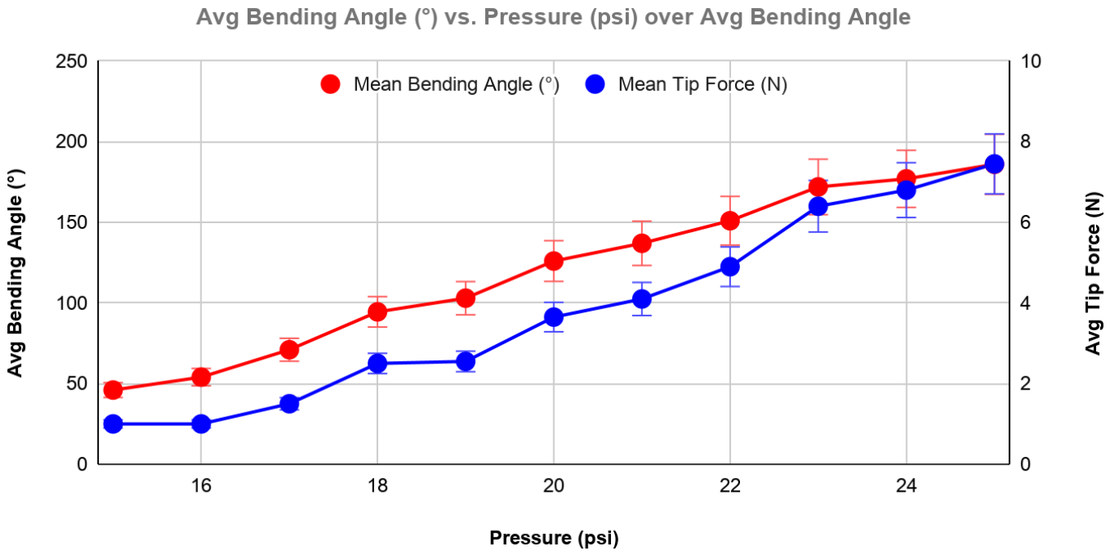

Figure 2: *Mean tip force as a function of pneumatic pressure. Error bars represent ±1 standard deviation.*

Pressure (psi)	Mean Bending Angle (°) ± SD	Mean Tip Force (N) ± SD
15	46 ± 4.0	1.0 ± 0.2
16	54.3 ± 4.1	1.0 ± 0.1
17	73.3 ± 2.5	1.5 ± 0.1
18	94.3 ± 5.5	2.3 ± 0.3
19	101.7 ± 2.5	2.5 ± 0.15
20	126.3 ± 4.1	3.7 ± 0.4
21	135 ± 2.0	4.2 ± 0.1
23	174.7 ± 9.2	6.6 ± 0.7
24	176.3 ± 1.5	6.8 ± 0.1

Linear regression analysis revealed a strong positive relationship between pneumatic pressure and bending angle ($R^2 = 0.98$, $p < 0.001$), indicating that 98% of the variation in bending angle is explained by pressure. Similarly, a strong positive relationship was observed between pressure and tip force ($R^2 \approx 0.97$, $p < 0.001$).

These results indicate that pneumatic pressure is a statistically significant predictor of actuator performance, leading to the rejection of the null hypothesis.

Pressure and Bending

The data shows a clear positive correlation: as pressure increased from 15 to 25 psi, the bending angle increased by over 300%. The "jump" in bending was larger at lower pressures, likely due to the initial overcoming of the silicone's elastic resistance. This confirms the non-linear nature of hyperelastic materials.

Figure 1. Mean bending angle as a function of pneumatic pressure. Error bars represent ±1 standard deviation.

Figure 2. Mean tip force as a function of pneumatic pressure. Error bars represent ±1 standard deviation.

Force Generation

Tip force showed a nearly nine-fold increase. Interestingly, force growth became more pronounced at higher pressures. As the actuator reaches its maximum curvature, the internal pressure contributes more significantly to stiffness rather than further deformation, resulting in increased gripping power.

LIMITATIONS AND FUTURE IMPROVEMENTS

- **Hysteresis:** Soft materials often don't return to their exact original shape immediately after deflation (material fatigue). Future trials should include a "rest period" between tests.
- **Measurement Precision:** Manual angle measurement introduces human error. Utilizing **Computer Vision (OpenCV)** to track the actuator's centroid would provide more accurate, automated data.

This indicates a transition from deformation-dominated behavior to stiffness-dominated behavior, where additional pressure contributes more to force generation than curvature.

Strengths:

- Systematic 1 psi increments over a practical range (15–25 psi) enabled clear detection of non-linear transitions.
- Three repeated trials per level reduced random error and allowed reliable mean/SD calculation.
- Controlled setup with stabilization time and safety enclosure ensured replicability and researcher safety.

Limitations:

Material hysteresis (delayed return to original shape post-deflation) was not quantified. If inflation and deflation curves differ substantially (e.g., 5–15% angle variance common in silicone), the reported pressure-performance relationships apply primarily to single-stroke inflation, potentially limiting generalizability to cyclic operations and slightly overestimating consistent force in repeated use.

Manual digital protractor measurements introduce human error, especially at high angles (>150°). With typical 0.1° resolution but possible ±2–5° placement variability at curved positions, this could represent ~2–3% error relative to maximum observed angles (~187°), introducing minor systematic bias at higher pressures without affecting overall strong correlations.

Improvements:

Incorporate a 5-minute rest period between trials, quantified by measuring baseline (15 psi) inflation-deflation cycles before/after to directly calculate hysteresis magnitude (e.g., % angle recovery).

Replace manual protractor with computer vision (e.g., OpenCV tracking of actuator centroid or key points at 30 fps) for automated, sub-degree precision and curvature calculation, reducing measurement error to <1°.

CONCLUSION

This investigation aimed to examine how pneumatic pressure influences both the bending angle and tip force of a soft robotic actuator, addressing the challenge of quantitatively characterizing soft actuator performance identified in previous research.

The results demonstrate a strong positive and non-linear relationship between pressure and both output variables with the R2 value is 0.98. As pressure increased from 15 psi to 25 psi, the actuator exhibited a significant increase in bending angle, reaching a maximum of 187°, alongside a corresponding rise in tip force to 7.5 N. These findings are consistent with the theoretical behavior of hyperelastic materials, where deformation is initially dominated by elastic resistance and later transitions toward increased structural stiffness. These findings support the alternative hypothesis and lead to the rejection of the null hypothesis.

Importantly, the data confirms that pneumatic pressure serves as an effective and controllable input parameter for tuning actuator performance. At lower pressures, small increases result in large changes in deformation, while at higher pressures, the actuator exhibits greater force generation due to reduced additional curvature and increased internal resistance.

This study contributes to the existing body of knowledge by providing experimental evidence that links pressure not only to actuator motion but also to force output, thereby addressing the gap identified in prior research. Overall, the findings support the viability of pneumatic soft actuators as adaptable systems capable of both precise movement and controllable force generation.

The results of this investigation have several important real-world applications, particularly in areas where safe and adaptive interaction is required.

Medical Robotics:

The ability to precisely control both bending angle and force makes soft pneumatic actuators highly suitable for minimally invasive surgical tools. For example, endoscopic devices can navigate complex internal pathways while applying controlled force to avoid damaging sensitive tissues.

Agricultural Automation:

Soft robotic grippers can be used to harvest delicate crops such as fruits and vegetables. Based on the findings, pressure can be adjusted to optimize grip strength without causing bruising, improving efficiency and reducing waste.

Rehabilitation and Assistive Devices:

Wearable soft robotic systems, such as rehabilitation gloves, rely on controlled actuation to assist patient movement. The demonstrated relationship between pressure and motion enables customizable assistance levels tailored to individual users.

Industrial Automation:

In manufacturing environments, soft grippers can handle irregular or fragile objects that traditional rigid robots cannot manage safely. The ability to modulate force at higher pressures enhances gripping reliability without compromising object integrity.

Future Engineering Design:

The quantitative relationship established in this study can be used to inform the design of control systems, where pressure input can be calibrated to achieve specific motion and force outputs, improving the precision and predictability of soft robotic systems.

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The influence of nationality on athletes' sport preferences and performance

ABSTRACT

The research question for this paper is: "To what extent does nationality shape athletes' sport preferences and affect their performance levels?" To answer this question, a mixed-method approach was used, combining a review of existing studies with an interview. The study explored how environmental and physical factors associated with nationality influence both the sports athletes choose and their level of performance.

The research focused on influences such as sport popularity and national identity, as well as environmental factors including access to facilities, funding, and coaching systems. Physical and biological considerations, such as body composition and training conditions, were also examined while avoiding assumptions that nationality directly determines success. An interview with an experienced D1-athlete coach provided real-world insight into development within different national contexts. The findings indicate that nationality plays an indirect role in shaping athletic outcomes. While nationality strongly influences exposure, opportunities, and development systems, individual differences in athletes also play a role. Athletes' dedication, training, and access to opportunities also contribute to their performance. Overall, nationality acts as a framework that shapes pathways rather than a direct determinant of success.

INTRODUCTION

Sport is a phenomenon; however, patterns of participation and success differ significantly among countries. The source *The Impact of Cultural Values on Sporting Excellence: A Study of Nations Worldwide* confirms that elite sporting success is unevenly distributed, with nations like the USA, United Kingdom, France, Japan, and China appearing in the top quartile of absolute performance while others, particularly those with lower economic development, show much lower participation and success rates. These patterns raise questions about the role of nationality in shaping both athletic preferences and performance levels.

My research question: "To what extent does nationality shape athletes' sport preferences and affect their performance levels?"

H_0 (Null Hypothesis): Nationality does not play a significant role in the preference and performance of athletes.
H_a (Alternative Hypothesis): Nationality plays a significant role in the preference and performance of athletes.

Nationality is defined as the legal status or state of belonging to a specific nation, typically acquired by birth, descent, or naturalization. However, nationality extends beyond identity and reflects a combination of cultural values, economic conditions, and access to resources. (Cambridge Dictionary, Vocabulary, and Wikipedia). These factors influence the types of sports individuals are exposed to from an early age as well as the opportunities available for training and development. For example, according to the study *The Impact of Cultural Values on Sporting Excellence: A Study of Nations Worldwide*, regression analysis of 112 countries confirms that economic development (GDP per capita) is a highly statistically significant predictor of elite sporting success (p-value = 0.030). Countries that heavily invest in sports often develop structured systems that support athletes from early participation to elite competition. This creates environments where success in sports becomes more likely, which means that athletes from wealthier countries may have better access to stadiums, gyms, tracks, swimming pools, and expensive equipment, while athletes from poorer countries may have limited access to certain participations.

Cultural identity also plays an important role in sport excellence. Cultural identity in sports is defined by how the nation and individuals define themselves in an athletic perspective. This can be associated with athletes' unique disciplines affecting their participation in specific sports. For instance, according to IMPAKTER, "sports such as cricket and Australian Rules Football (AFL) are woven firmly into the national identity..." This cultural influence in sports can encourage young athletes to participate in certain sports from an early age, encouraging interest and long-term development in young athletes.

To overcome these drawbacks, many athletes migrate. Africa is the largest "supplier" of athletes, with Kenya and Ethiopia at the top. Between 1998 and 2016, 36% of all recorded nationality swaps involved African athletes moving to non-African countries. Leaders in these regions often struggle to keep talent at home as they cannot provide the food, salaries, and training facilities offered elsewhere.

METHODOLOGY

This study employed a mixed-method research design combining a review of existing studies with an interview. This approach was selected to provide both an understanding of existing research and detailed insights from real-world experience. The purpose of this review was to test my hypothesis with data online and a professional who had real-life experience.

The review involved analyzing articles, sports science research, and credible reports related to athletic performance and national sport systems. Sources were selected based on relevance to the research question, reliability of publication, and recency. Using the data collected, claims were developed. The claims were based on 10 reliable sources.
The search term or core concepts I used for efficient research were: Nationality, Genetics and "Innate Factors", Socio-Cultural Factors, and Nationalism in Sports. These terms were used as the starting point in the research. The beginning of these terms narrowed down the ideas to further research. For instance, Sources that studied how a nation's GDP affects factors: access to training facilities; availability of professional coaching, quality of sports science support; and overall investment in athlete development, introduced the significance of cultural identity for athletes. This, in turn, led to further investigation into how cultural identity and national pride shape athlete motivation, public support, and government investment in sport.

These claims were then supported with evidence. However, to further test the validity of these claims through an expert perspective, an interview was conducted. Some claims that were tested were: "Country's GDP (average wealth) has a positive impact on athlete development"; "Cultural identity plays a significant role in the performance and participation of athletes in sports"; and "Sports tied to national identity are more likely to be played." In order to test these claims, the interview's questions were developed with the goal of inspecting the research's claims. The interview's questions were made sure to ask about perceived or observed factors, NOT racial/ethnic stereotypes, avoiding any bias towards the claims. In addition to avoiding biased or leading questions, several ethical considerations were taken into account during the interview process. First, informed consent was obtained from the participant, ensuring that they were fully aware of the purpose of the research, how their responses would be used, and their right to withdraw at any time without consequence. This helped establish transparency and respect for the participant's autonomy. The interviewee's credibility was an important factor in strengthening the overall reliability of the research. The interviewee was selected based on their insight and experience within the field, ensuring that their insights were based on real-world experiences rather than personal opinions. By utilizing perspectives from a qualified professional, the study was able to expand beyond theoretical or secondary data and include reliable and practical experience-based evidence.

The interview was conducted in a structured format, with predetermined and follow-up questions to allow a more easier experience for the interviewee to elaborate on his answer. This gave the interview consistency and focus around all topics discussed. Responses were recorded and later analyzed by identifying recurring themes and patterns that either supported or refuted the existing claims, but the interview also conveyed new facts, such as a role model.

The coach interviewed explained how the popularity of sports causes young athletes to have different role models. For instance, due to Australian players succeeding internationally, like in the NBA, the sport receives more attention and gains in popularity. His process of claim analysis allowed for a clearer comparison between secondary research findings and primary data collected from the interview. To ensure reliability of the information, were cross-referenced with sources to check for alignment or discrepancies. This helped maintain objectivity and prevented the research from being biased towards only evidence that supported the alternative hypothesis.

Overall, the combination of both secondary and primary research methods strengthened the validity of the research by providing a more comprehensive understanding of the factors that influence athletic performance and sport preference across different national contexts.

RESULTS

Theme	Number of Sources	Quotations from Coach	Analysis
Economic Factors	8/10	"Countries with more funding can provide better facilities and long-term athlete support."	8 of 10 sources linked national wealth to access to training resources and development systems
Coaching Quality & Support Systems	7/10	"High-level coaching and consistent support systems make a major difference in athlete outcomes."	7 of 10 sources emphasized professional coaching and structured programs
Cultural Identity & Nationalism	6/10	"Athletes often feel pride representing their country, which can influence effort and commitment."	6 of 10 sources connected national identity to motivation and participation
Popularity of Sport by Nation	5/10	"Sports that are culturally valued in a country tend to have more participants and better performance levels."	5 of 10 sources noted higher participation in culturally significant sports
Genetics / Innate Factors	4/10	"Physical traits can play a role, but they are not the only factor in success."	4 of 10 sources referenced biological or genetic influences

The findings of this study were organized into five themes: Economic Factors, Coaching Quality & Support Systems, Cultural Identity & Nationalism, Popularity of Sport by Nation, and Genetics / Innate Factor. These themes are narrowed from being referenced in both the literature review and the interview. The results are summarized in the table above.

The most frequently mentioned theme was economic factors. 8 out of 10 sources discussed the impact of national wealth on athlete development. These sources consistently referenced access to different facilities, funding, and long-term training systems. Coaching quality and support systems were also identified. Appearing in 7 different sources, this theme was highlighted in the studies as the role of professional coaching, structured development programs, and access to sports science resources. Cultural identity and nationalism were mentioned in 6 different sources, conveying how national pride and representation influence athlete participation and commitment.

The popularity of specific sports within a nation appeared in 5 sources, which is described by how cultural preferences in certain sports influence the participation rates among athletes, correlating with performance levels. Lastly, genetic or innate factors were referenced in 4 sources, typically correlating physical attributes with certain sports.

During the interview, one theme was discussed in depth. The theme "Popularity of Sport by Nation" was discussed in relation to multiple factors identified in the study. The interviewed Coach described how sports that attract larger audiences tend to generate increased revenue through more fan engagement. He noted that higher viewership and fan support can lead to greater involvement from corporations and sponsors. The sponsors invest in the league and teams, which tends to lead to athlete development from the increased funding within the sport. For instance, in his home country, basketball was described as an expanding sport, with references to increased facility development and financial involvement from both government and corporate sources.

DISCUSSION

The results of this study provide insight into the extent to which nationality influences athletes' sports preferences and performance levels by highlighting different factors: structural, cultural, and biological factors. Although it cannot be concluded that a single factor alone determines athlete success, the findings suggest that nationality shapes the environment in which athletes develop throughout their lives.

The most prominent finding from the sources was the significance of economic factors, with 8 out of 10 sources linking national wealth to athlete development. This suggests that most countries with high GDPs tend to provide greater access to facilities, coaching, and long-term development for athletes. This connects back to the research presented in the introduction. The idea that disparities in global sporting success are not random is supported. Rather, the success is influenced by the unequal distribution of resources. Athletes in wealthier nations are more likely to benefit from structured systems that support elite performance, which is why there exists nationality swapping in the sporting field.

Coaching quality and support systems were also identified as a major contributing factor, appearing in 7 different sources. This reinforces the idea that athlete performance is not solely dependent on individual ability, but also on the quality of guidance and facilities provided. Access to professional coaching and sports science resources allows athletes to train more efficiently and consistently. This aligns with the existing research that emphasizes the importance of institutional support in developing athletes and further supports the study's hypothesis.

Cultural identity and nationalism also emerged as important influences. 6 different sources referenced their impact on athlete motivation and participation. The findings suggest that a sense of national pride or cultural expectation may influence athletes' commitment to sport. This connects to the broader idea that sport is not only a physical activity but also a social and cultural phenomenon. Countries with strong sporting traditions may encourage higher participation rates, increasing the likelihood of producing elite athletes. Thus, nationality influences not only access to resources but also the social environment that shapes athlete behavior.

The theme "Popularity of Sport by Nation" further strengthens this argument by demonstrating how cultural preference and economic investment are interconnected. Both the literature review and the interview with the Coach highlighted how popular sports tend to receive more attention, funding, and participation. This creates a cycle in which increased popularity leads to greater investment, which then enhances development opportunities for athletes. As a result, athletes are more likely to succeed in sports that are widely supported within their country. This finding supports the hypothesis that nationality influences sport preference, as individuals are more likely to participate in sports that are culturally prominent and accessible.

In contrast, genetic or innate factors were referenced less frequently, appearing in only 4 sources. While these factors may contribute to physical advantages in certain sports, the results suggest that they are not the primary determinant of success. Instead, they function alongside external factors such as training, environment, and opportunity. This challenges the idea that athletic success is largely predetermined by biology, and instead supports a more complex view in which environmental and societal influences play a greater role.

The interview with a former Division 1 coach provided additional support for these findings by offering real-world observations that aligned with the literature. His responses emphasized the relationship between sport popularity, funding, and athlete development, reinforcing the idea that national systems and cultural context significantly impact performance outcomes. By incorporating an expert perspective, the study was able to validate patterns identified in secondary research and strengthen the overall reliability of the conclusions.

Overall, the data support the hypothesis that nationality plays a significant role in shaping both sport preference and athletic performance. However, this influence is indirect, operating through economic resources, cultural values, and institutional support systems rather than nationality itself being a direct cause. This suggests that differences in athletic success between countries are better explained by access to opportunities and support rather than inherent ability alone.

CONCLUSION

Based on the findings of the study, the alternative hypothesis, Nationality influences athletes' sport preference and performance levels, is supported to a significant extent. But primarily through external factors rather than inherent abilities. The research shows that economic resources, access to quality coaching, and structured support systems play a major role in shaping athletic development. Countries with greater financial capacity (higher GDP) are more likely to provide athletes with better opportunities through better facilities and training opportunities, which contribute to higher performance levels.

In addition, Cultural identity and National pride influence which sports are more commonly played within a country. This affects the participation rates. Sports that are more popular receive more attention, thus, more funding and institutional support, which further enhances athlete development in those areas. While genetic or innate factors may contribute to performance, they were less consistently supported across the data.

Overall, the results of the research indicate that nationality shapes the environment and opportunities available to athletes, affecting both their sport preferences and their ability to succeed.

EVALUATION / LIMITATIONS

This study has limitations. The use of an interview limits the generalizability of the findings as it reflects the perspective of one individual. Additionally, the reliance on sources introduces potential bias depending on the quality of the research. However, the interviewee was extremely reliable in relating my research. As an experienced D1-athlete, the coach was a former D1 athlete, former NBL coach, and a current CHANge CEO who teaches other NBA coaches leadership. His interview provided the research great insight into the research question and a true opinion from an expert in this field. Throughout the research, attempts were made to contact additional professionals, including NBA athletes and Korean soccer players; however, no responses were received. This highlights the challenge of participant accessibility in research and the limitations it can impose on data collection. For future research, incorporating a broader sample of interviews from athletes and coaches across multiple countries to increase the reliability and representativeness of the findings will be a great way to shift the research into the next level.

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Exploring surface sanitization effectiveness of various Vietnamese medical-grade antiseptics on *escherichia coli* colonies

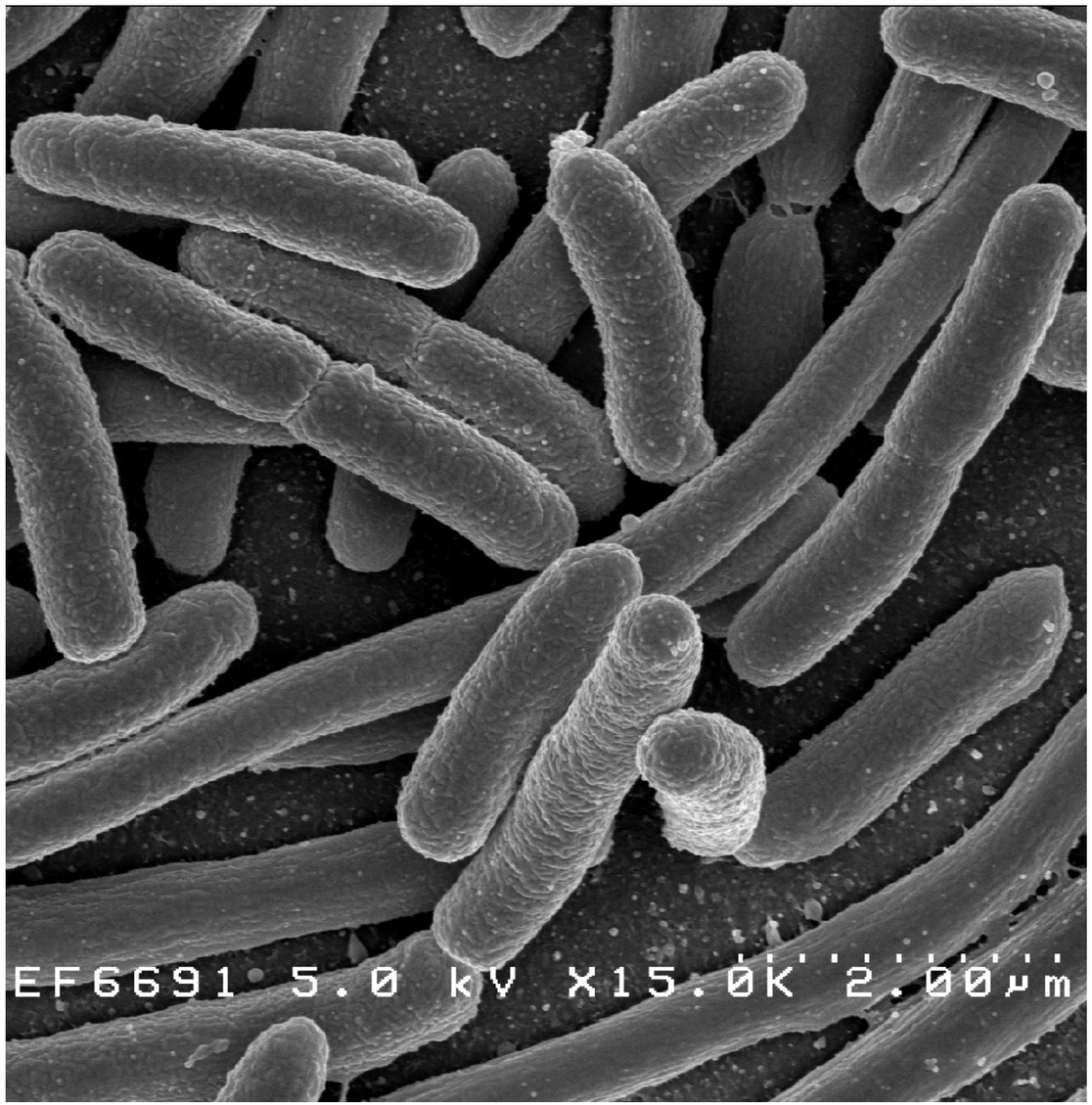


Image provided by National Geographic Education from National Geographic

ABSTRACT

In the modern medical community, the discovery and application of antiseptics has been crucial in treating wounds and prevention of complicated healing processes as well as contraction of other life-threatening bacterial infections. Antiseptic types may differ across countries and communities depending on availability, cultural, and development as well as accessibility to specific antiseptics. To resolve the debate regarding whichever widely-available antiseptic in Vietnam can combat *Escherichia coli* (referred to as *E. Coli* in this paper) external (SSTI) wound infections the best, we've taken Benzalkonium Chloride, Hydrogen Peroxide, Isopropyl Alcohol, and Povidone Iodine to test whichever antiseptic can clear the highest surface area of surface-infected *E. Coli*. The data was collected through a simplified Kirby-Bauer disk method and analyzed using ANOVA, resulting in Benzalkonium Chloride having both the highest average surface area disinfected, and the lowest variance in results being Povidone Iodine. Hydrogen Peroxide and the Control variable shows 0 effect on the *E. Coli,* which was taken into consideration in limitations. The sample size is n = 29. The F value is 45.58, our critical value at 4 degrees of freedom at a significance level of a= 0.05 is ~2.76. Our P value is <0.00001, concluding that we can reject the null hypothesis.

INTRODUCTION

In this paper, the exploration of antiseptics focuses on efficiency of the antimicrobial effects on killing a simulated *E. Coli* wound infection on a plate of Luria Burtani agar. The intention is to focus on which type of the selected medical antiseptics (chosen by commonality in usage with regards to the context of Vietnamese Hospitals, more specifically Central-Southwards provinces) kills the biggest surface area of *E. Coli* within the timeframe (experimentation and incubation) of 24 hours.

The purpose of this paper is to be able to find out which specific antiseptic would kill the largest area of a simulated *E. Coli* culture infection within the time it is given. When taken into a real world context, these findings would help support local hospitals and medical environments knowledge on which antiseptic is best to be equipped to limit the progression of a bacterial infection in open wounds.

With this finding, the data gathered will be reported to the Saigon South International School's Nurse and Medical team. If findings differ from the current status quo (measured by the school's current medical kit) then changes may be persuaded to be installed.

There are a few notable obstacles regarding potential findings. First, selected antiseptics and their findings will need to take into consideration that this is a simulation due to ethics of human experimentation which does not allow full guarantee and accuracy of antiseptic effectiveness on a real skin wound. Additionally, selected antiseptics are comprised of different chemicals, and different chemicals have different pain sensitivity to the skin–meaning that though Isopropyl Alcohol and Benzalkonium Chloride may be of the same usage, the harshness reactivity to the derma layers may be different, which is important to take into account of pain level when treating patients in a medical context.

To start with understanding antiseptic behavior, we must understand the process of infection. An external wound common to many circumstances of everyday life is defined by an injury that breaks the skin or other body tissues, causing puncture and breaking the tissues with the consequences to exposure to external microorganisms, microparticles, and air to the open gap. (medlineplus.gov, 2007)

There are many types of wounds identified in the medical field, categorized by their behaviors and causation of the wound.

Acute wounds are wounds that occur suddenly but progresses through the expected healing stages. This can be exemplified through simple paper cuts or scratches.

Chronic wounds are wounds that undergo a significantly longer process of healing, which can be identified by the body's inability to heal properly or slower than usual. These wounds may take up to 4-6 weeks to heal properly possibly due to infection.

Surgical wounds are wounds that have been inflicted by surgical instruments during medical procedures, such as scalpel incision. This may be exemplified through non-sanitary conditions of such tools (coloplast professional)

In context, according to the goal of this paper, which is to review the effectiveness of first-aid wound antiseptics, we are taking account of acute wound conditions for simplicity and efficiency. Such injuries that can be applied to the findings in this paper are simple skin cuts or scratches that result in an open wound with no blood, due to the absence of blood in our experiments for hygienic purposes.

Understanding the healing and infection progress of human skin

Healing

When the skin heals after an open cut or wound, there are 4 general steps that they go through. 1) hemostasis: The skin is cut and internal tissues are exposed. Any breaks involving the epidermis layer and below would cause blood to rush to the wound in attempts to clot and close off the cut. White blood cells are sent to the infected area to fight the contamination of bacteria and microorganisms, which causes red swelling. 2) Inflammation: a sign that macrophages and neutrophils are assisting to help close the wound, clean the wound, and clean of any debris or bacteria that may impact the process of healing. White blood cells that are dead after fighting bacteria may be visibly prevalent on the wounds as white "flesh". 3) proliferation: the wound is built with connective tissue in order to promote tissue growth to repair the cut and cover the wound. New skin cells, called keratinocytes, crawl across the wound bed in order to create a new skin barrier (epidermis). 4) remodeling: during the remodeling stage, epithelial tissue is formed in a moist healing environment to protect the wound and promote healing. The more appropriate, stronger collagen is aligned with the body's healing, and extra blood vessels are slowly discarded.

Infection

When a cut is enacted onto skin, the body's immune system does not necessarily react immediately but waits for the condition of how the wound is first handled within 24-48 hours of the injury.

Stage 1: Contaminated wound
Stage one begins with the open wound exposed to the external microorganisms, microparticles, and the air. When this happens, bacteria are present in the wound and attach onto the external surface. Currently, the numbers do not multiply, and a host response is not provoked. Healing carries on on par with the average expected healing rate so long the colony is contained.

Stage 2: Colonized wound
When a wound is exposed and bacteria presence is indicated and multiplied but not threatening. The multiplication affects the layers of the skin and may trigger a delay in healing as the infection takes place. Antimicrobials would not be indicated in this stage. Such indications of this stage is when wounds produce odor and yellow pus, as well as areas of white/yellow dead 'flesh' (dead white cells combating the colonization).

Stage 3: Local-infection wound
A locally infected wound indicates the presence and multiplication of bacteria contaminating the open wound, with invasion under an agent (usually viral bacteria) that accesses the dermis layer which triggers a host response. A local infection is often provoked through unsanitized, humid conditions that stay viable for infection to happen. The effects that are produced by the bacterial attack are harmful to the host, healing is impaired, and the immune system attacks the wound aggressively.

Stage 4: Systematic infection and sepsis
At this stage, the wound has been colonized and the bacteria has entered through either the vascular or lymphatic systems. When the bacteria invades the bloodstream, the immune system receives a distress signal and overloads the body with symptoms, which may inherently cause septic, which is oftentimes (in this context) due to systematic inflammation which causes widespread blood vessel leakage. Because of the coverage of the immune system, the bacteria may circulate throughout the body, causing a chain of reactions that sets off throughout the body, consequences including possible organ failure and death. Healing is severely impaired. (The Royal Children's Hospital Melbourne, 2023)

Common culture bacteria

On the human skin, more than 90% of the bacteria living on the surface of the epidermis can be found in either four major phyla:

- Actinobacteria (52%)
- Firmicutes (24%)
- Proteobacteria (~16%)
- Bacteroidetes (~6%)

Depending on the environment–humidity and moisture, for example–and area of the skin, such bacterial compositions on the skin may be different. For example, a swab of mouth bacteria may be drastically different than a swab of nailbeds. Thus, it is important to note that this difference may impact the applicability of the findings in this paper. (Menitti et. al, 2025)

ESCHERICHIA COLI

Given the availability and the commonality of *E. Coli* infections, bacteria *E. Coli* had been chosen as the available proxy for the staphylococcaceae. Due to safety concerns and limitations regarding access to such samples of the bacteria, *E. Coli* infections, most common as a transient contaminant which is often passed through unhygienic conditions and/or fecal matter. Such limitations due to this proxy usage will be addressed later in the Limitations section. Soft-tissue infections (skin) caused by *E. Coli* are severe, but rare. Hence, it is important to tread the investigation with this note that the findings are not just circumstantial but also the potential application. For the sake of this experiment, *E. Coli* will be regarded as a gram negative bacteria that contributes to viral skin infections.

According to the national library of medicine, Pubmed central (US), there have been several reports associating E. Collie with SSTI wounds and active infections. "*E. Coli* was found to be the causative agent of neonatal omphalitis, cellulitis localized to lower or upper limbs...infections after burn injuries, and others." (Petkovšek et. al, 2009)

E. Coli has been shown to be a causative agent to the external layer of skin despite being known to have been previously isolated and mostly prominent on the lower intestines of mammals or shedded feces in the environment. Though *E. Coli* is also titled as the third-most prevalent isolated species, "preceded solely by Staphylococcus Aureus and Pseudomonas." (Petkovšek et. al, 2009)

Additionally, *E. Coli* has been the leading cause of death and sepsis, being the most common pathogen cause of death relevant to antibiotic resistance, especially among older adults. Chronically ill and/or infected patients have a higher risk of immune and lymphatic system compromisation due to increased likelihood of antibiotic resistance. (Vu et. al, 2023)

Reaction to the antiseptic

E. Coli is a gram-negative bacteria, making it harder to treat with antibiotics when it is associated with surgical or burn wounds that penetrate skin layers. The difference between gram-negative and gram-positive bacteria is that gram-negative have 2 layers of phospholipid layers instead of, creating a harder barrier for antibiotics to be effective despite having a thinner peptidoglycan wall. Typical skin infections from *E. Coli* do not differ from other usual bacterial infections. Swelling, purulent drainage, delayed healing, increased odor and erythema around the wound. (Ki et. al, 2008)

Example cases of how *E. Coli* strands interact with antiseptics, description:

- PVP-1 (10%) Povidone Iodine 10% - rapidly kills *E. Coli* via oxidative damage, often achieving full bacterial action within 5 minutes or less. (Nazarchuck et. al, 2025)
- Alcohol (eg. 70% isopropyl) denatures bacterial protein and dissolves its lipids quickly, rendering the cell to its death. (Nazarchuck et. al, 2025)

INTERVIEW

In an interview to address the situational context and the possible usage of the findings from this paper, 2 medical professionals have been selected: **Dr. Nguyen Thanh Phat** and **Ms. Kerry-Anne Brint.**

Brief introduction:
Dr. Nguyen Thanh Phat *is a doctor with a Vietnamese medical degree holder of General Practice (family medicine) from the Hue University of Medicine and Pharmacy. He is also a retired practitioner at the University Medical Hospital of Ho Chi Minh City.*

Ms. Kerry Anne Brint *is a registered nurse with an Honors Bachelors and Masters of Science degree from the University of Plymouth, UK. Additionally, she is also in the process of finishing her Masters of science in Global Health and Infectious diseases. She currently works as the Head of the Medical Team for the Saigon South International School, Vietnam.*

Dr. Phat claims that the antiseptics he most commonly use under the jurisdiction of the hospital's guidance are Povidone Iodine, most commonly referred to as Betadine 10%, and oftentimes for specifically the purpose of disinfecting the skin area to prepare for surgery. Surgeons in the University Medical Hospital often swab the area of skin with Povidone Iodine in order to cleanse the surface in preparation for incisions, which is crucial that minimal hostile bacterial colonies remain on the open area. Another common antiseptic that is more frequently used for treating open wounds and disinfecting the excess leakage of pus and matter is Chlorhexidine Glutamate. This antiseptic is the most versatile and he can see many of the surgeons using these to sanitize open wounds from injuries. Its application is mostly found on the area around the skin. However, Natri Chloride (NaCl) or saline water is also a common disinfectant in the hospital, especially for moving out debris and small microparticles stuck on the wound. Wounds are oftentimes flushed using this solution and can be better treated for topical ointments and antimicrobials when needed.

Ms. Kerry Anne had explained the school's choice behind Benalkonium Chloride: this antiseptic is FDA approved (under school western standards and global recommendations) low irritant (for those with skin sensitivity) and has strong infection control. Additionally, the small packages of individual wipes create a higher level of hygiene as well as control wastage. During her years of experience as a nurse, using Iodine as an antiseptic provided a strong, sometimes hurtful result for the patient. She debunked that the painful "stinging" sensation is not a sign that an antiseptic is "working"; rather, it is important to evaluate that a mild reaction is normal, but prolonged pain may be an indication of damaged nerves instead of skin. She also claims that Hydrogen Peroxide is only best applied to certain wounds and is overused, most effective when it is deep cleaning wounds. Depending on the injury, saline solutions may also be as effective.

Scientific Investigation: *E. Coli* on AB Agar antiseptics test

In order to fully conduct an answer to our paper, investigating on which antiseptic is the most effective at cleansing areas of infection within a confined space of time, we are led to the foundations of this medical investigation:

Research question: what locally-used antiseptic in Vietnam sanitizes the highest surface area of *E. Coli* SSTI (Skin and Soft Tissue Infection) within 24 hours?

Hypothesis: If a 3% Povidone Iodine Solution is applied to an *E. Coli* SSTI (expressed through a proxy using a swabbed agar petri dish), then it will sanitize the highest surface area of the infection within 24 hours compared to other local antiseptics through its penetrative sustained-release mechanism through oxidative stress and maintaining efficacy resistance against neutralizing pus and wound exudate.

METHODOLOGY

Using a simplified version of the Kirby-Bauer disk diffusion method, we experiment with the different antiseptics as our independent variables to investigate which one produces the largest surface area of bacteria cleanse (indicated to no presence/blank spots on a swabbed dish). These blank spots are called "zones" and will be measured in specificity using an organic measurer apparatus from ImageJ.

The Kirbry-Braur disk diffusion method can be explained below by the American Society For Microbiology: "By the early 1950s, most clinical microbiology laboratories in the United States had adopted the disk diffusion method for determining susceptibility of bacteria to antimicrobials. Each lab modified the procedure to suit its own needs, which included using different types of media, inoculum concentration, incubation time, incubation temperature, and concentration of the antimicrobial compound.

"The purpose of the Kirby-Bauer disk diffusion susceptibility test is to determine the sensitivity or resistance of pathogenic aerobic and facultative anaerobic bacteria to various antimicrobial compounds in order to assist a physician in selecting treatment options for his or her patients."

Independent Variable(s) trials:

1. Povidone Iodine
2. 100% 2-Isopropyl Alcohol
3. 3% Hydrogen Peroxide
4. 0.13% Benzalkonium Chloride

Control Variable trials:

1. Control (none applied)

Controlled Variable(s)

Temperature
Incubation can Temperature is controlled consistently under 36 degrees Celsius under the 24 hours of incubation all 29 petri dishes were in. Fluctuations of temperature before incubation were not accounted for due to the shortened time of preparation that allowed. Additionally, temperature did not impact results before or after the incubation. This is reflected in the Limitations section as a potential source for variance amongst results.

Lighting Conditions
All lighting conditions remain consistent over the duration of the incubation period and experimentation procedure. Light–espeically UV light–may impact results by stall bacteria growth or kill it completely, creating inconsistent settings for incubation and data collection.

All measures stay consistent throughout the procedure listed below. In order to create the most accurate results, the following listed measurements have been utilized throughout the entire duration of the experiment if needed.

Equipment used:

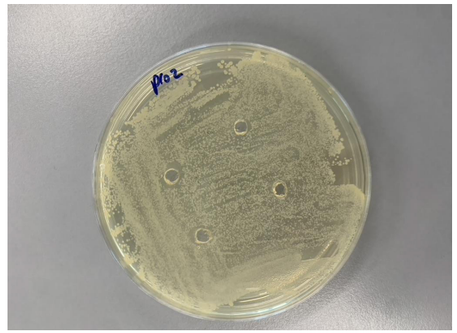
- Luria Burtani (LB) agar, ~10ml per dish, 290 mL total
  - Ratio of 30:1 mixture of water to LB
- Sterile cotton swabs (x5)
- Petri dish (diameter size: 9cm) (x29)
- Testing tube
- Pipette (x3) cut into even-sized lengths to create a makeshift bacterial cork borer
- Sterile teasing needle
- *E. Coli* concentrate (0.5 mL)
- NaCl saline water (0.85%)
- 0.6 mL Povidone Iodine 3%
- 0.6 mL 100% 2-Isopropul alcohol
- 0.6 mL Hydrogen Peroxide 3%
- Benzalkonium Chloride towelette 5" x 7" 0.13% (1 pc)[1]
- Marker for labeling the petri dishes
- Sterile iris scissor
- Medical gloves
- Heat-resistant safety gloves
- Safety goggles
- Sanitary mask

Pre-procedural steps

1. Heat up and prepare the Luria Burtani agar. Handle using the heat-resistant safety gloves
2. Pour up to ⅓ of the petri dish depth. Repeat for all petri dishes.
3. Let the agar for approximately 3-4 hours.
4. Mix 0.5 mL of *E. Coli* concentration into a small test tube
5. Mix 0.5 mL of NaCl (0.85%) into the small test tube alongside the *E. Coli* concentration
6. Mix the two solutions by swirling the test tube for 30 seconds.
7. Taking a sterile cotton swab, dip ½ of the bud of the cotton swab into the dilution and begin streaking the agar.
   a. The recommendation is to use a uniform lawn to get consistency throughout the dish.
8. Cut a pipette approximately 2 cm up by the tip. Measure that the diameter is approximately 0.25 cm of the new opening from the pipette. This will be used as the makeshift cork borer for the agar.

[1] *Benzalkonium Chloride was applied as a towelette in an agar well–this may contribute to distinct variance amongst results later named in Limitations.*

9. Using the cut pipette, center 4 spots and puncture the agar evenly spread across the petri dish.



Povidone trial photo (taken from this experiment)

10. Repeat for all petri dishes until done.

Procedural steps

1. Prepare povidone iodine solution by extracting through a pipette.
2. Upon immediate removal of the agar jelly made from the cork borer, pour in the povidone iodine solution using a pipette with sufficient amount to fill but not overflow the cylindrical well.
3. Repeat the procedure until all 4 "wells" of the agar have been done in the petri dish.
4. Label the petri dish beginning with numerical order as well as the codename of the concentrate.
5. Repeat the procedure for 5 other petri dishes, totalling 6 povidone iodine dish trials.
6. Prepare 100% 2 Isopropyl Alcohol by extracting through a pipette.
7. Upon immediate removal of the agar jelly made from the cork borer, pour in the Isopropyl Alcohol solution using a pipette with sufficient amount to fill but not overflow the cylindrical well.
8. Repeat the procedure until all 4 "wells" of the agar have been done in the petri dish.
9. Label the petri dish beginning with numerical order as well as the codename of the concentrate.
10. Repeat the procedure for 5 other petri dishes, totalling 6 isopropyl alcohol dish trials.
11. Prepare 3% Hydrogen Peroxide by extracting through a pipette.
12. Upon immediate removal of the agar jelly made from the cork borer, pour in the hydrogen peroxide solution using a pipette with sufficient amount to fill but not overflow the cylindrical well.
13. Repeat the procedure until all 4 "wells" of the agar have been done in the petri dish.
14. Label the petri dish beginning with numerical order as well as the codename of the concentrate.
15. Repeat the procedure for 5 other petri dishes, totalling 6 hydrogen peroxide dish trials.
16. Prepare the trials for benzalkonium chloride by taking a benzalkonium chloride towelette and a sterile scissor.
17. Remove the benzalkonium chloride towelette from its packaging.
18. Cut the towelette into small square pieces (0.5 x 0.5 cm) using the iris scissors.
19. Cut until you have 24 small squares of benzalkonium chloride towelette.
20. Using a sterile teasing needle, put one square into every individual circular opening created earlier in the petri dish.
21. Repeat until all gaps have been filled with the square towelette piece in one petri dish.
22. Repeat for all 6 petri dishes.
23. Label the petri dish beginning with numerical order as well as the codename of the concentrate.
24. Label the remaining 5 petri dishes with control and in numerical order for the control trials.
25. Cover all petri dishes.
26. Let incubate for 24 hours.

DATA & CONCLUSION

Photo from CET Scientific PTe Ltd "Kirby Brauer Disk Diffusion Test"

DATA FINDINGS

Trials	Povidone iodine - IO3	Isopropyl alcohol - PRO	Hydrogen peroxide -	Benzalkonium chloride - BENZ	Control aka none - control
1	4	2	0	4	0
2	4	3	0	4	0
3	4	2	0	4	0
4	4	0	0	4	0
5	4	1	0	4	0
6	4	4	0	4	0

Table 1: *Manifestation chart–proportion of change visibly present*

0 indicates no bacterial disinfection was visibly present.
1-4 indicate that there are a number of trials out of 4 that show prevalent signs of disinfection.

Trials	Povidone iodine - IO3	Isopropyl alcohol - PRO	Hydrogen peroxide -	Benzalkonium chloride - BENZ	Control aka none - control
1	1.282	0.837	0	3.573	0
2	1.049	0.139	0	2.711	0
3	0.543	0.147	0	5.194	0
4	0.702	0	0	2.867	0
5	0.586	0.289	0	2.460	0
6	0.712	1.484	0	3.653	0

Table 2: *Average surface area disinfected for ANOVA*
*round to 3 significant values, all units being cm

Individual sub-trial experiment raw data

*** all data has been subtracted 0.153 cm2 from original surface area to exclude the cylindrical gap in the agar for the Kirby-Bauer disk diffusion experimental procedure.**
*** All units are cm2 unless listed otherwise.**
*** X indicates that no signs of antiseptics had killed the streaked *E. Coli.***

Dish #	Petri dish 1	Petri dish 2	Petri dish 3	Petri dish 4	Petri dish 5	Petri dish 6
Circle 1	0.452	1.284	0.283	1.350	0.335	1.452
Circle 2	0.374	1.663	0.463	0.252	0.322	0.072
Circle 3	2.077	0.312	1.003	1.965	0.294	0.331
Circle 4	2.223	0.938	0.394	0.242	1.391	0.991

Table 3.1: *Povidone iodine*

Dish #	Petri dish 1	Petri dish 2	Petri dish 3	Petri dish 4	Petri dish 5	Petri dish 6
Circle 1	1.439	0.094	0.176	X	1.154	0.409
Circle 2	1.191	0.182	0.297	X	X	1.314
Circle 3	X	0.281	0.114	X	X	2.531
Circle 4	X	X	X	X	X	1.683

Table 3.2: *Isopropyl alcohol*

Dish #	Petri dish 1	Petri dish 2	Petri dish 3	Petri dish 4	Petri dish 5	Petri dish 6
Circle 1	X	X	X	X	X	X
Circle 2	X	X	X	X	X	X
Circle 3	X	X	X	X	X	X
Circle 4	X	X	X	X	X	X

Table 3.3: *Hydrogen peroxide*

Dish #	Petri dish 1	Petri dish 2	Petri dish 3	Petri dish 4	Petri dish 5	Petri dish 6
Circle 1	3.551	2.343	4.640	1.684	2.536	2.356
Circle 2	3.457	1.889	7.384	3.453	2.942	3.771
Circle 3	3.442	3.151	4.525	3.405	2.656	4.626
Circle 4	3.841	3.462	4.228	2.924	2.156	3.921

Table 3.4: *Benzalkonium chloride*

Dish #	Petri dish 1	Petri dish 2	Petri dish 3	Petri dish 4	Petri dish 5	Petri dish 6
Circle 1	X	X	X	X	X	X
Circle 2	X	X	X	X	X	X
Circle 3	X	X	X	X	X	X
Circle 4	X	X	X	X	X	X

Table 3.5: *None (control)*

Group	Povidone Iodine	Isopropyl Alcohol	Hydrogen Peroxide	Benzalkonium Chloride	Control
Sum	4.874	2.896	0	20.458	0
Mean	0.812	0.483	0	3.410	0
Variance	0.083	0.354	0	1.018	0

Table 4: *Group statistics*

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic
Between Groups	53.076	4	13.269	45.58
Within Groups (Error)	7.278	25	0.291	
Total	60.354	29		

Table 5: *ANOVA table*

H_0 = There is no difference and that the mean surface area disinfected across all 5 variables are the same.

H_a = there is a difference and that the mean surface area disinfected across all 5 variables are not the same.

- **The F-statistic: F value = 45.58.**
- **The Critical Value:** For df (4,25) at a significance level of α= 0.05, the critical value is approximately **2.76.**
- **The p-value:** The p-value is < **0.00001.**

The larger the ratio, represented by the Value F, the more likely that each group has different means from each other and the more likely to reject the null hypothesis. Thus, we can conclude from our F value of 45.58 that our F statistic is significantly larger than our critical value, to which we reject the null hypothesis. There is a statistically significant difference in the antiseptic effectiveness of these chemical compounds.

LIMITATIONS

Limitation: Study design proxy

Concern: the study's designated proxy is not a valid replacement when comparing our intended bacteria (staphylococcus aureus) and our actual proxy bacteria (escherichia coli). There are drastic differences between these bacteria that may affect antimicrobial traits we observe, thus may make our results not as feasible. While *E. Coli* is gram-negative, Staph. Aureus is gram-positive. To note, gram-positive bacteria are considerably harder to neutralize with antiseptics due to their thicker peptidoglycan wall.

Address: this study design proxy is a limitation that cannot be overwritten under the consideration of lab safety, biohazard safety, and overall preservation of the bacteria. Thus, to address this concern, our study design proxy can not be alleviated but can be re-considered under different circumstances where *E. Coli* is the main focus of the experimentation.

Limitation: Application method of Benzalkonium Chloride

Concern: Benzalkonium Chloride was not applied in liquid form like the rest of the test variables; instead, it was applied using towelettes infused with the antiseptic solution, and in the experimentation we had cut the towlettes up in pieces and left them in circular gaps of the agar, allowing the agar to soak the benzalkonium chloride through the towelettes.

Address: the next time, benzalkonium chloride should be applied in proper liquid form as the towelettes may serve as a confounding variable. The liquid may not be fully absorbed through the agar due to the physical barrier, which may undermine the results.

Limitation: Hydrogen peroxide anomaly

Concern: Hydrogen peroxide, despite being commonly used as an antiseptic for daily usage, shows zero signs of its antimicrobial effect on the *E. coli*. The effectiveness was not manifested in a single trial, rendering hydrogen peroxide (3%) as an ineffective trial.

Address: This may be due to Hydrogen Peroxide being extremely sensitive to its short-term effect, where the compound is extremely easy to evaporate under a short amount of time. Because the results were waited for 24 hours before measuring, the Hydrogen peroxide must have evaporated, rendering the results invisible since the compound does not remain. Additionally, we can revise the independent variables to ensure each one is long-lasting antibiotics.

Limitation: Human skin microbiome mimicry

Concern: the agar gel is not accurate in representing the human skin microbiome and microorganisms culture. The agar assumes that the area is filled only with a layer of *E. Coli* manifestation. This does not serve its true purpose of simulating an area of open wound to justify the antimicrobial effects with the selected antiseptic.

Address: due to limitations of bacterial access, we were unable to mimic the human skin microbiome in order to fully represent an open wound on skin. To further this notion, the mimicry of human skin microbiome is difficult as everyone has a slightly different composition–to further specify the environment where the bacteria is manifest will force our research to be narrowed down in generalization. Lastly, we have to consider that the LB agar is not necessarily supportive of all types of bacterial growth, inhibiting some due to its compatibility. Microorganisms and bacterias may compete and end up inhibiting growth of others, and in a limited lab environment with student-level access to technology, there is no real guarantee of a true balance that perfectly mimics the human skin microbiome to a considerable approximation.

DATA ANALYSIS/DISCUSSION

The experimental results demonstrate that Benzalkonium Chloride (0.13%) was the most effective antiseptic, achieving the highest mean disinfection area of 3.410 cm^2. This performance aligns with its role as a strong infection control agent and its FDA approval for high-standard medical environments. In contrast, Povidone Iodine and Isopropyl Alcohol yielded significantly lower disinfection areas of 0.812 cm^2 and 0.483 cm^2, respectively. While literature suggests Povidone Iodine kills *E. Coli* via rapid oxidative damage and Isopropyl Alcohol denatures proteins , their lower performance in this study may be attributed to the specific 24-hour incubation period or the "sustained-release" requirements of Iodine that may not have been fully realized in the agar well method. Notably, Hydrogen Peroxide (3%) showed zero effect , which correlates with its clinical description as being best suited for deep-cleaning specific wounds rather than broad-spectrum surface disinfection. The statistical significance of these differences is confirmed by an F-statistic of 45.58 and a P-value < 0.00001, allowing for the rejection of the null hypothesis.

CONCLUSION

To conclude, our hypothesis has not been supported, and we reach the conclusion that **between independent variables, Benzalkonium Chloride (0.13%) has sanitized the highest surface area of *E. Coli* within 24 hours.**

This conclusion had been reached through our data analysis. We used ANOVA to compare the means of 24 trials per antiseptic for 4 types of antiseptics, and included 20 trials for our control variable (none applied). Our results are clear: the average of surface area disinfected from highest to lowest is listed: Benzalkonium Chloride (3.410), Povidone Iodine (0.812), Isopropyl Alcohol (0.483), and Hydrogen Peroxide and the Control (which were both an average of 0 cm2 disinfected).

From lowest to highest, the following antiseptics showed the variance within the data of their trials. Povidone Iodine (0.083), Isopropyl Alcohol (0.354), and Benzalkonium Chloride (1.018). Hydrogen Peroxide and the Control trials had 0 variation due to insufficient data.

Our P-value is less than 0.00001, which is significantly less than our alpha, crossing our threshold and allows us to reject the null hypothesis, which assumes that there is no difference between the results of different antiseptics.

Our statistics show that there is a statically significant difference between our experimental variables. From this study we can conclude that, under the pretense of the conditions that our *E. Coli* was cultivated under 24 hours with antiseptics applied, the antiseptic that cleaned the widest surface area was Benzalkoninum Chloride (0.13%).

We can positively add that the current Saigon South International School daily medkit utilizes the antiseptic bacterial wipes that was used for the experiment. Therefore, we can guarantee that from the conclusions, the school is correctly using the best disinfectant in order to clean the surface area of infected wounds.

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Does plant-based protein supplementation produce comparable gains in lean body mass to whey protein during resistance training?

This study was designed to determine whether plant-based protein supplementation produces similar gains in lean body mass (LBM) to whey protein supplementation during resistance training. A narrative review was conducted using five peer-reviewed randomized controlled trials that directly compared plant-based and whey protein under controlled training and dietary conditions. Lean body mass increased for both groups across all studies throughout the duration of experimentation. Across studies, both plant-based and whey protein groups demonstrated similar increases in lean body mass, with no statistically significant differences observed ($p > 0.05$). This analysis suggests that protein source alone does not independently influence muscle hypertrophy when daily protein intake and resistance training variables are controlled. Hence, plant-based protein supplementation can serve as an effective alternative to whey-based protein powder for supporting muscle growth.

INTRODUCTION

Resistance training combined with sufficient protein intake is universally recognized as the most effective strategy for increasing muscle mass and strength (Morton et al., 2018; Phillips & Van Loon, 2011). Muscle hypertrophy, defined as an increase in muscle mass and thickening of muscle fibers, occurs when muscle protein synthesis (MPS) exceeds muscle protein breakdown over time (Phillips, 2014). The importance of protein is that it provides essential amino acids to stimulate MPS, specifically leucine, which activates the mammalian target of rapamycin (mTOR) pathway (Norton & Layman, 2006; Kimball & Jefferson, 2006).

Traditionally, whey protein is considered the "gold standard" for muscle growth due to its rapid digestion and high leucine content (Tang et al., 2009). Several metabolic studies demonstrate that whey protein can stimulate MPS to a greater extent than certain plant-based proteins when controlling for total protein intake (Tang et al., 2009; Yang et al., 2012). Naturally, this has led to the assumption that whey protein is the superior protein source for long-term hypertrophy.

However, a sharp increase in MPS does not necessarily lead to long-term gains in lean body mass (Mitchell et al., 2014). A narrative review of the resistance training studies suggests that total daily protein intake is the primary contributor to hypertrophy, rather than the specific protein source alone (Morton et al., 2018). Some studies have reported minimal to no difference between animal and plant-based protein sources when protein intake is controlled (Messina, 2016).

Several randomized controlled trials have done side-by-side comparisons between plant-based proteins (e.g., soy, pea, rice) with whey protein during resistance training programs (Joy et al., 2013; Babault et al., 2015). Many of these studies controlled total protein intake at approximately 1.6 $g \cdot kg^{-1} \cdot day^{-1}$ and standardized training volume and frequency (Morton et al., 2018).

Despite the growing evidence, there is still lingering debate about whether plant-based protein supplementation produces proportional lean mass gains to whey protein under controlled conditions. Therefore, this study synthesizes available randomized trials to analyze whether protein source independently influences muscle hypertrophy.

Research Question

In resistance-trained adults, does plant-based protein supplementation produce comparable gains in lean body mass to whey protein supplementation when protein dose and training volume are controlled?

Null Hypothesis (H_0):
There is no significant difference in lean body mass gains between plant-based and whey protein supplementation during resistance training.

Alternative Hypothesis (H_a):
Whey protein supplementation produces significantly greater lean body mass gains than plant-based protein supplementation during resistance training.

METHODOLOGY

Study Design

This study used a narrative review design to compare gains in lean body mass (LBM) with plant-based protein supplementation versus whey protein supplementation during resistance training. The analysis summarizes findings from peer-reviewed randomized controlled trials that directly compared plant-based and whey protein under controlled dietary and training conditions.

Participants

Studies were included if they met the following criteria:

1. Involved adult participants (≥18 years),
2. Implemented a structured resistance training program lasting at least 8 weeks,
3. Compared plant-based protein supplementation (e.g., soy, pea, or rice protein) with whey protein supplementation, and
4. Reported pre- and post-intervention measurements of lean body mass.

A total of five randomized controlled trials were included in the final analysis, with a combined sample size of approximately 250–300 participants across studies.

Materials / Instruments

Lean body mass was measured using validated body composition techniques, including:

1. **Dual-energy X-ray absorptiometry (DXA):**
   DXA uses low-dose X-rays at two different energy levels to differentiate between bone, fat mass, and lean body mass. Muscle mass is estimated from the lean tissue component, allowing for precise measurement of changes in whole-body and regional muscle mass.
2. **Air displacement plethysmography (BodPod):**
   The BodPod measures body composition by calculating body volume based on air displacement within a sealed chamber. Muscle mass is not measured directly but is estimated by determining body density and then separating fat mass from fat-free (lean) mass.
3. **Ultrasound-based muscle thickness measurements:**
   Ultrasound uses high-frequency sound waves to visualize muscle tissue and measure its thickness at specific anatomical sites. Changes in muscle thickness are used as an indicator of muscle hypertrophy over time.

Variables

Independent Variable (IV):
Type of protein supplementation (plant-based vs whey protein)

Dependent Variable (DV):
Change in lean body mass (kg) following the intervention period

Controlled Variables:

1. Total daily protein intake (where reported)
2. Resistance training frequency and duration
3. Study duration (8–12 weeks)

Procedure

Studies were identified through a review of peer-reviewed literature on protein supplementation and resistance training. Relevant studies were selected based on the following criteria:

1. Adult Participants
2. Type of protein supplementation
3. Implementation of a structured resistance training program
4. Direct comparison between plant-based and whey protein supplementation

Data from the selected studies were manually reviewed and extracted, which included sample size, duration, type of protein supplementation, and changes in lean body mass.

Ethics

Institutional review boards have previously approved all research compiled. All data were publicly available and had been previously peer-reviewed. Data collection did not involve direct experimentation with individuals in this paper. Only studies that met all the listed criteria and were verified through the published sources were included in the analysis. The results were then summarized and compared across studies to identify patterns in outcomes.

Statistical/Analysis Plan

Statistical analysis was performed to assess changes in lean mass across studies. This study summarizes the reported statistical outcomes from the selected randomized controlled trials rather than conducting new statistical analysis. Statistical significances (p-value) were analyzed to determine the significance of the lean mass difference between plant-based protein supplementation and whey-based protein supplementation. Statistical significance was evaluated at $0.05 = \alpha$ across all studies.

RESULTS

A total of five randomized controlled experiments ($n \approx 250–300$ participants) were included in the analysis to assess the effects of whey- and plant-based protein supplementation during resistance training.

Across all studies, both plant-based and whey protein groups demonstrated increases in lean body mass (LBM) following the intervention periods (defined as the duration of the experiment, 8–12 weeks).

Across studies, both plant-based and whey protein groups demonstrated similar increases in lean body mass, with no statistically significant differences observed

Study	Protein Type Compared	Duration (weeks)	ΔLBM Plant (kg)	Δ LBM Whey (kg)	p-value
Hevia-Larraín (2021)	Vegan vs Omnivorous	12	+1.2	+1.2	> 0.05
Joy (2013)	Rice vs Whey	8	+2.5	+2.7	> 0.05
Babault (2015)	Pea vs Whey	12	+2.0	+2.1	> 0.05
Lynch (2020)	Soy vs Whey	12	+1.3	+1.4	> 0.05
Banaszek (2019)	Pea vs Whey	8	No significant change	No significant change	> 0.05

Table 1: *The table illustrates the comparison of mean lean body mass gains between plant-based and whey protein groups across studies.*

Inferential Statistics

Across all included studies, no statistically significant differences were observed between plant-based and whey protein supplementation in lean body mass (LBM) gains.

For all comparisons:

$p > 0.05$, indicating no significant difference between groups

Therefore, the null hypothesis (H_0) was not rejected.

This pattern was consistent across all five studies, regardless of protein source (soy, pea, rice) or study duration.

Patterns and Trends

1. All included studies demonstrated that both protein sources promoted increases in lean body mass following resistance training.
2. Under the controlled experimental conditions, volume and protein intake, the gains in lean body mass between different protein sources were similar.
3. Leucine-matched studies showed near-identical results. Studies controlling for amino acid composition reported the smallest differences between groups.

Summary

The results show that when resistance training volume and protein intake are controlled, plant-based supplementation produces similar increases in lean body mass to whey-based supplementation. Across all studies included, both groups consistently showed an increase in lean body mass over the experimental duration, indicating that protein supplementation aids in muscle hypertrophy no matter the protein source.

Most importantly, no statistical significance was found between plant-based and whey protein groups in any of the studies ($p > 0.05$), in which it can be concluded that there are no major differences in lean muscle mass. The variation of differences was very minute, indicating that protein source alone is not a significant factor in muscle growth under controlled conditions.

These findings suggest that under controlled conditions, protein dosage and training volume, plant-based protein supplementation can provide just as much support in increasing lean body mass in resistance-trained adults.

DISCUSSION

The findings of this study suggest that total protein intake plays a larger role in influencing muscle hypertrophy rather than the specific protein source consumed (Morton et al., 2018). Across the randomized controlled experiments analyzed, both plant-based protein and whey-based protein supplementation produced no significantly different increase in lean body mass when protein intake was matched at approximately 1.6 $g \cdot kg^{-1} \cdot day^{-1}$ and resistance training variables were controlled (Joy et al., 2013; Babault et al., 2015). This analysis matches with existing research indicating that sufficient intake of essential amino acids, rather than the protein source alone, is the primary driving factor of muscle protein synthesis in the long run (Phillips & Van Loon, 2011).

It is evident that whey protein has been shown to produce a sharper increase in protein synthesis due to its higher leucine content and faster digestion rate (Tang et al., 2009). However, this short-term increase does not equate to a greater long-term hypertrophy (Mitchell et al., 2014). This is because the body can only contain a certain amount of leucine (leucine threshold). Once the threshold is reached, additional intake does not further enhance muscle growth (Norton & Layman, 2006). Hence, despite whey protein producing a faster anabolic response, plant-based protein achieves comparable hypertrophy when protein intake is controlled.

CONCLUSION

Ultimately, the evidence suggests that when protein intake and resistance training are controlled, plant-based and whey protein result in similar increases in lean body mass. Despite whey protein's potential to produce a sharper increase in muscle synthesis response, that does not translate into greater long-term hypertrophy outcomes (Mitchell et al., 2014).

All in all, to answer the research question, protein source cannot independently and extensively influence muscle hypertrophy when protein intake is sufficient. The null hypothesis (H_0) was supported, as no statistically significant difference was observed between plant-based and whey protein supplementation. These findings indicate that individuals can effectively achieve muscle growth with adequate protein intake, regardless of the protein type, whether it's plant-based protein or animal-based protein.

EVALUATION / LIMITATIONS

This narrative review has several strengths regarding the reliability and validity of the findings. First, only peer-reviewed randomized controlled trials (RCTs) were included in the analysis, which is the epitome of reliable experimental research. This means confounding variables were reduced through a process called random assignment. Additionally, many of the studies controlled for daily protein intake and resistance training volume, allowing for an accurate comparison between plant-based and whey protein supplements. By doing this, the influence of the protein source on muscle synthesis is isolated as the primary independent variable.

However, there are several limitations that should be considered. One major limitation is the relatively small number of studies analyzed, with only five randomized controlled trials meeting the inclusion criteria. With a small sample size, the generalizability of the findings will be reduced as study-specific factors have an increased influence on the results. Furthermore, the studies were at most 12 weeks, their long-term hypertrophy can not be fully captured. As a result, the findings are likely to underestimate differences that would have emerged from longer training periods.

The variability in the measurement tools used to assess lean body mass also poses a limitation to this narrative review. Different studies contained different methods, and each method varied in levels of precision and margin of error. For example, DXA provides highly accurate estimates of body composition, whereas ultrasound measurements are dependent on how the machine is being operated. This inconsistency could lead to higher variability in the results and affect the comparison between the studies.

Additionally, the types and quality of plant-based protein differ across different studies. (soy, pea, and rice protein). Each source had different amino compositions and digestibility, all of which affect muscle protein synthesis. Hence, categorizing the sources all under the same category of protein type may potentially rule out small but significant effects of each source.

To account for these limitations in future research, longer-duration randomized trials with larger samples should be conducted. Furthermore, the chosen protein sources should control for amino acid profiles, specifically leucine content, to allow for a more accurate comparison between protein sources. Lastly, the measurement tool should have utmost accuracy in measuring lean body mass, like the DXA, across all studies to improve reliability and reduce variability. All improvements would lead to a clearer understanding of protein source and its influence on muscle hypertrophy.

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How do different nutrient compositions in sports drinks affect muscle function and performance in adolescent athletes?

ABSTRACT

This study aimed at comparing the influence of various nutrients present in sports drinks on muscle performance and physiological reactions during exercise was carried out. The research utilized an experimental repeated measures design whereby young athletes were asked to drink 200 mL of fluids with different compositions of nutrients prior to performing standardized push-ups. Repetition numbers, heart rate, and rate of perceived exertion were used as indicators of performance. The data obtained through the analysis were subjected to descriptive and inferential statistics such as ANOVA. It appeared that no statistically significant differences existed between the various groups receiving different types of drinks ($p > 0.05$). Thus, sports drink composition is unlikely to have any effect on muscle performance in the course of exercise.

Keywords: sports drinks, muscle performance, exercise physiology, nutrients, hydration

INTRODUCTION

Background and Context

Currently, Sport drinks have become a common source for athletes to maintain their hydration. Sport drinks have become very common among athletes because they are used to promote hydration, increase the availability of energy, and enhance performance in exercises. The drinks are formulated using different ingredients including carbohydrates, electrolytes, caffeine, and vitamins to enhance muscle contraction during exercises.

The carbohydrates found in sports drinks are used to restore the stored glycogen in muscles while enhancing exercise performance. Electrolytes in the drink include sodium and potassium; the two electrolytes help to increase hydration and enhance muscle contraction. Sports drinks also include B-complex vitamins, which aid in the process of metabolism, and caffeine to enhance stimulation of the central nervous system. However, the scientific evidence may vary depending on the type of exercise, nutrient composition, and individual

Knowledge Gap

While many sports drinks are marketed as being able to improve performance in athletes, there is a disconnect between the claims made and the scientifically proven physiological benefits. Consumers tend to depend on name recognition and advertisements instead of comparing the effects of various nutritional mixes.

The purpose of this study is to test the effect that various sports drink nutrition mixes can have on muscle function performance and physiology during exercise.

Research Question

How do different nutrients of sports drinks optimize muscle function and performance in adolescent athletes?

Hypothesis

H_0 (Null Hypothesis):
Different sports drink nutrient compositions have no significant effect on muscle performance, heart rate response, or perceived exertion during exercise.

H_a (Alternative Hypothesis):
Sports drinks containing performance-related nutrients such as carbohydrates, electrolytes, caffeine, or vitamins will produce measurable differences in muscle performance, heart rate response, or perceived exertion.

METHODOLOGY

This study employed a controlled experimental design combined with a post-exercise survey to evaluate the effects of different beverage compositions on exercise outcomes. Participants completed standardized exercise trials after consuming beverages representing distinct nutrient profiles, enabling direct comparison of performance, physiological response, and perceived exertion across conditions.

A repeated-measures (within-subject) design was implemented, in which each participant completed multiple trials under different beverage treatments. This approach minimized the impact of individual variability and allowed for more reliable comparison of results across conditions.

Participants

Participants consisted of high school adolescent male athletes aged 15–18 who regularly engage in physical exercise in the gym, most engage in weightlifting at least 3 hours a week. A purposive sampling approach was used to recruit individuals with sufficient baseline fitness to safely perform the exercise tests. All participants had no prior or active health issues and no recent caffeine use prior to engaging in the experiment. The final sample included 10 participants, and no participants had any prior or active health issues.

Materials and Instruments

Beverage Treatments

The following beverages were selected to represent distinct nutrient profiles commonly found in sports drinks:

- Revive – electrolyte-focused beverage
- Red Bull – source of caffeine and B-vitamins
- Gatorade – carbohydrate-based sports drink
- Control – no performance beverage (baseline condition)

Each beverage was administered in a randomized order to minimize potential order effects and experimental bias.

Measurement Instruments

The following tools were used to collect performance and physiological data:

- Push-up endurance tests—the maximum amount of pushup able to do in a set
- Smartwatch (e.g., Apple Watch) for heart rate monitoring
- Manual pulse measurement (15-second count multiplied by four)
- Rate of Perceived Exertion (RPE) scale (1–10) via post-exercise surve

Variables

Independent Variable

In this study, the independent variable is the type of beverage consumed before doing exercises. All the beverages were selected based on the distinct nutrients contained in them, with all being common in sports drinks. For example, Gatorade contained carbohydrates, while Revive and Red Bull were made up of electrolytes. The control variable is the lack of consumption of any of the beverages before doing exercises.

Dependent Variables

The dependent variables include exercise performance and physiological responses to the exercise. Muscle performance can be measured by the number of push-ups performed during the exercise. Physiological responses can be measured using heart rate, measured in beats per minute, and RPE on a scale of one to ten.

Controlled Variables

Some variables were controlled in order to make the test more reliable. They include the amount of beverage taken during each exercise, which is around 200 milliliters. The time between exercise sessions was set to five to ten minutes, and longer durations would be allowed if fatigue is a problem. The instructions for doing the exercises were also constant in all exercise tests. There is also consistency in the use of the measuring equipment and methods used. The testing environments were limited to comparable indoor locations, including the SSIS gym, SSIS dance room, and Riverpark apartment gym, to reduce environmental variability.

Procedure

The participants were randomly divided into the different groups and were asked to consume 200ml of their assigned drink before participating in a trial. They were given a 5-15 minutes time frame before participating in a push up test to allow for the absorption of the drink and other physiological changes caused by the beverage. Then participants participated in a push up test to exhaustion and all repetitions were recorded. In addition, heart rate and RPE scores were assessed right after completing the test. For heart rate measurement, smartwatches were used if participants had one, otherwise, heart rates were recorded by manually taking pulse for 15 seconds and then multiplied by 4. Perceived exertion was evaluated based on the RPE scales immediately after the test.

Each participant participated in several trials in the repeated measures design. The interval between tests was not less than 5-10 minutes, and in case if needed trials were done at two separate occasions (with 12-24 hours interval). After the tests, the subjects completed a questionnaire to evaluate their perceived level of energy and fatigue.

Experimental Images

The following images depict the standardized push-ups that were used for testing throughout the experiment. Participants were engaged in doing push-ups in indoor settings ranging from gym environments to home settings. This was done prior to their consent to ensure that participants were engaged in actual exercise situations yet under standardized conditions. Some participants did not wish to be filmed, so not all participants were filmed. In all cases, the subjects adopted a plank position where their hands were spread at shoulder width.

A number of images of various participants at various stages during the push-up exercise are included to show both the eccentric (downward) phase and concentric (upward) phases of push-ups. The variety of environments depicted ensures that the experiments were carried out under varied conditions yet consistent in methodology.

ETHICAL CONSIDERATIONS

This research abided by the principles of ethics. All the subjects had given consent before engaging in the experiment and were completely informed about the objectives, process, and duration of the study. They were assured that they had the right to withdraw from the study at any stage without being penalized. This study was carried out in an environment that was safe and not intimidating, and the subjects were given the opportunity to abandon the test when they felt overwhelmed or tired.

STATISTICAL ANALYSIS

For analysis of the collected data, both descriptive and inferential statistical approaches have been used. Mean and standard deviation values were calculated for each measured parameter to compare performance, physiology and effort perception between subjects. One-way ANOVA test was conducted to find if there were statistically significant differences between beverages. If needed, Tukey's HSD post hoc test was conducted for investigation of particular comparisons. Also, the effect size (η^2) was calculated to estimate the significance of differences.

RESULTS

The results for exercise performance, physiological effect, and the perception of effort demonstrated variations between the individuals and different types of drinks consumed. Exercise performances done by the individuals were different, varying from about 3 to 32 depending on the physical capability of the individual and the type of treatment received. The heart rates measured after doing exercise ranged between about 80 and 128 beats per minute. RPE values varied on an average of between 5 and 8.5.

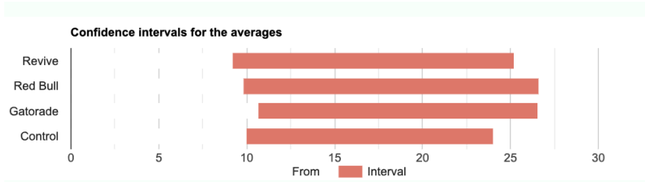
There existed a slight variation in the average value obtained between different beverage types, but there also existed a very big variation in each individual sample. Using the analysis of variance (ANOVA), the differences in the variables observed could not be significantly associated with the type of drinks used.

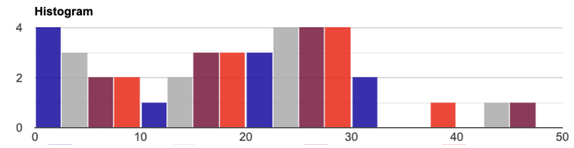
Groups:	Revive (Reps)	Red Bull (Reps)	Gatorade (Reps)	Control (Reps)
	22	25	20	24
	32	29	29	29
	20	22	22	24
	8	13	10	7
	4	5	8	3
	8	7	10	12
	9	10	5	10
	10	7	15	10
	37	41	40	31
	22	23	27	20
Skewness	0.640	0.669	0.664	0.093
Excess Kurtosis	-0.798	0.339	0.608	0.442
Mean	17.2	18.2	18.6	17
S Value	11.193	11.736	11.100	9.81

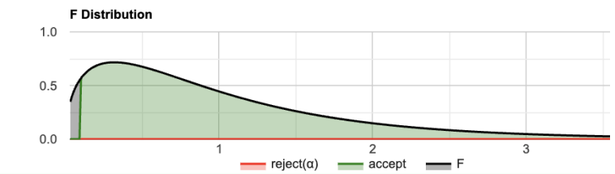
Table 1: *Repetitions ANOVA test Results*

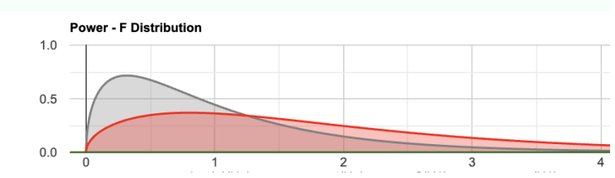
The following is the output results generated by the Anova test calculator based on the total number of push-up repetitions done for each of the ten sets of participants. These results show that Gatorade, the energy drink that contains carbohydrates, had the highest effect on boosting performance as the participants were able to perform an average of 18.6 push-ups, which is the highest effect; followed by Red Bull with an average of 18.2 push-ups, Revive with 17.2 repetitions, and lastly the control group who performed 17 repetitions.

But, based on the statistical significance level of 0.05, the null hypothesis was not rejected while the alternative hypothesis was rejected since the high p-value shows the absence of evidence to reject the null hypothesis, and not the other way around.









One-Way ANOVA Test (df = 3, 36, right-tailed)

1. Hypotheses

H_0: All group means are equal.
H_a: At least one mean is different.
Since p-value > α, we fail to reject H_0. There is no statistically significant difference between the group means.

2. P-value

p-value = **0.985204**. This very large p-value strongly supports H_0 and indicates a high probability of Type I error if H_0 were rejected.

3. Test Statistic

F = **0.0494748,** which lies in the non-rejection region.

4. Effect Size

f = **0.064** (small).
η^2 = **0.0041,** meaning only 0.4% of variation is explained by group differences.

5. Tukey HSD

No significant differences between any pair of group means.

Groups:	Revive (bpm)	Red Bull (bpm)	Gatorade (bpm)	Control (bpm)
	103	117	111	106
	88	64	110	110
	110	113	111	128
	120	112	115	105
	124	100	80	124
	120	100	100	120
	102	92	100	100
	100	100	98	97
	116	118	96	108
	120	128	110	100
Skewness	-0.667	-1.20	-1.148	0.655
Excess Kurtosis	-0.798	0.339	0.608	0.442
Mean	17.2	18.2	18.6	17
S Value	11.193	11.736	11.100	9.81

Table 2: *Heart-rate ANOVA Test Results*

Source	DF	Sum of Square	Mean Square	F Statistic	P-Value
Groups	3	406.6	135.533	0.770	0.504
Error	36	6129	170.25		
Total	39	6535.6	167.580		

One-Way ANOVA Test (df = 3, 36, right-tailed)

1. Hypotheses
H_0: All group means are equal.
H_a: At least one mean is different.
Since p-value > α, we fail to reject H_0; there is no statistically significant difference between the group means.

2. P-value

p-value = **0.504154**. This relatively large p-value supports H_0 and suggests insufficient evidence to detect differences among groups.

3. Test Statistic

F = **0.796084**, which lies in the non-rejection region.

4. Effect Size

f = **0.26** (medium).
η^2 = **0.062**, meaning 6.2% of the variation is explained by group differences.

5. Tukey HSD

No significant differences between any pair of group means.

Groups:	Revive	Red Bull	Gatorade	Control
	5	6	7	7.8
	6	7	7	7
	7	7	7	6
	7	6	6	7
	6	6.7	6	4
	6	7	5	4
	8	8	7	8
	7	7	8	8
	7	7	7	8
	8.5	8	8.6	8
Normality	0.553	0.073	0.367	0.007

Table 3: *RPE ANOVA Test Result*

Source	DF	Sum of Square	Mean Square	F Statistic	P-Value
Groups	3	0.287	0.09	0.745	0.973
Error	36	45.887	1.275		
Total	39	46.174	1.184		

One-Way ANOVA Test (df = 3, 36, right-tailed)

1. Hypotheses

H_0: All group means are equal.
H_a: At least one mean is different.
Since p-value > α, we fail to reject H_0; there is no statistically significant difference between the group means.

2. P-value

p-value = **0.973059**. This very large p-value strongly supports H_0 and indicates no evidence of differences among groups.

3. Test Statistic

F = **0.0749886**, which lies in the non-rejection region.

4. Effect Size

f = **0.079** (small).
η^2 = **0.0062**, meaning 0.6% of the variation is explained by group differences.

5. Tukey HSD

No significant differences between any pair of group means.

DISCUSSION

It can be seen from the results obtained for all three variables analyzed (exercise performance, RPE, and physiological response in form of heart rate) that there was no statistical difference between the groups tested in terms of the type of drink consumed.

In relation to exercise performance (measured by repetitions), there were slight differences in mean values, with some types of drinks such as those containing carbohydrates and/or electrolytes resulting in somewhat higher means. Yet, a one-way ANOVA returned p>0.05, thus making these differences insignificant from the standpoint of statistics. Moreover, the rather high standard deviations for the groups suggest a large variance in individual results, which may have influenced the obtained outcomes negatively.

Finally, regarding heart rate, there was also little variability among groups with mean values ranging from 103 to 110 beats per minute. Even though the Revive and control group mean values were slightly higher than those for Red Bull and Gatorade, ANOVA analysis shows that this difference is insignificant (p=0.504), and the effect size ($\eta^2 \approx 0.062$) indicates that beverage type explained a small percentage of variance.

When it comes to RPE, the results showed even greater consistency among all groups, with the means being around 6.7-6.9. In ANOVA test, we got an extremely high value (p = 0.973), which indicates virtually no significant influence of different beverages on participants' subjective perception of the effort. While some variations and anomalies could be detected, they did not really affect trends.

As for our assumptions, they held true in all datasets – our data was normally distributed and there were no violations of any assumptions needed for further analysis. Nevertheless, there are several reasons for insignificant results obtained in this experiment, such as relatively low sample size per group (n = 10), high variability within the group, and the use of identical ingredients (such as carbohydrates, electrolytes or stimulants) among the beverages tested. Furthermore, individual factors like fitness level, metabolic condition, caffeine sensitivity, as well as previous nutrition state might have had a greater influence than the type of the beverage used.

In general, though there were some slight trends showing that particular nutrients (like carbohydrates or caffeine) might influence participants' performance and perception of effort, they were too weak to become a noticeable factor.

These results support past studies, which have shown that the positive effects of sports drinks on performance might be dependent on certain contexts and might appear stronger for endurance and high-intensity workouts than short body-weight exercises.

CONCLUSION

The aim of this study was to assess the impact of various beverages' composition on the performance during exercise, physiological response, and perception of effort. With respect to all the dependent variables (i.e., repetitions, heart rate, and RPE), analysis revealed no significant effect of the independent variable (i.e., beverage type).

Even though there were slight differences between the groups' mean scores, the one-way ANOVA for each dependent variable produced values of p > 0.05, which means that there were no statistically significant differences between the groups. Besides, since the size of effects was rather small, the independent variable could account for little variance in the outcome.

Therefore, it can be concluded that within the limits of the current research, the influence of the independent variable on the results might be negligible; the impact of other factors (e.g., the participants' physiology and previous conditions) might prove to be much stronger.

Future studies will need to focus on increasing the sample size and controlling external factors such as diet and intensity of exercise. The results did not show any statistically significant difference, but they contribute towards creating a scientific understanding about the effectiveness of sports drinks. It is important to scrutinize the claims made by marketers in order to enhance athletic performance. This study helps in differentiating the subjective claims of enhanced performance from statistically proven performance enhancement.

EVALUATION AND LIMITATIONS

Strengths

The experiment utilized an experimental approach that made it possible to measure different beverages under similar conditions with the aim of reducing variability. Moreover, the adoption of several dependent variables (workout performance, heart rate, RPE) was essential in comprehensively investigating the effects of different sports beverages on exercise. The application of ANOVA analysis technique was also important because it offered objective means of measuring group differences.

Limitations

There were several aspects that needed consideration while evaluating the results obtained. To start with, the low sample size (n=10 per group) decreased the statistical power of the research. Moreover, self-reports were utilized to obtain data on such metrics as RPE, and this could have led to bias and inconsistency of the information collected. Individual peculiarities in terms of metabolic rates, fitness level, and caffeine tolerance might have resulted in higher variability.

Moreover, there is a possibility of inaccurate measurement caused by the use of wearables for heart rate monitoring since they cannot provide the same precision as clinical-grade devices. Another factor that needs mentioning is that the products used in the research were not isolated variables but consisted of several ingredients at once (e.g., carbs, electrolytes, and caffeine). Finally, the sample population used was represented mostly by teenage athletes only.

Future Improvements

Future research may enhance reliability and applicability by using a larger sample size to increase power and minimize the effect of outliers. In addition, a wider range of participants with different ages, fitness and athletic experience would increase generalizability of results.

Future experiments may look into various kinds and intensities of exercises and see if there is a change in the effects of the beverage consumed because of varied physiological stress on the body. Controlled environments, where pre-exercise nutritional intake and hydration are the same, will help in eliminating other variables affecting the outcome.

Biochemical measurements, such as measuring the level of blood glucose, electrolytes, or the hydration status of the body, can shed light on the actual reasons behind changes in performance. Testing of particular components of the beverages can reveal their specific effect on exercise performance.

Fatigue Effect from Repeated Trials

In addition to this, another weakness associated with the design of the experiment is that there can be a fatigue effect due to repeated trials over a short duration of time. The subjects had to do multiple sets of push-ups with different types of beverages within the same session. Even though there was a gap of 10 minutes in-between each trial, it is possible that fatigue had accumulated throughout this time.

As such, the last few trials, especially the third and fourth set of exercise, would have been done while the participants were already experiencing fatigue.

In other words, either fewer repetitions would have occurred or perceived exertion increased due to muscle fatigue and not necessarily because of the type of sports drink taken. This is another source of bias in the comparison of conditions.

Accounting for Fatigue Effects

Since the participants had to complete several exercise trials during the same experimental period, the risk existed that fatigue might affect their performance in subsequent trials. This potential confounding variable was controlled by introducing several procedural precautions into the study design. First, a rest period lasting 10 minutes was provided between the exercise trials, so that muscle strength could be partially restored prior to the following condition. Second, the sequence in which beverages were administered was randomized to avoid the scenario whereby the most fatiguing condition would always follow the previous ones.

Yet, despite these attempts at preventing fatigue from interfering with the results of the experiment, it cannot be ruled out that some influence of the accumulation of muscular fatigue on performance might still remain in place.

For instance, when four exercise trials were conducted during an hour, it can be assumed that muscle strength would decline over time, resulting in increased fatigue when completing the last set as opposed to the first one.

The effects of fatigue can be minimized by performing the trials on different days or restricting the total number of repetitions per day.

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How does rainfall intensity affect the aerodynamic efficiency of fixed-wing aircraft, and how can design adaptations improve flight performance and fuel efficiency under tropical rain conditions in Vietnam?

ABSTRACT

This study looks at the influence of rainfall intensity on the aerodynamic efficiency of fixed-wing aircraft, as well as what changes in the aircraft's design could improve efficiency and fuel efficiency in the tropical environment of Vietnam. This study used a "two-method" approach by combining existing aerodynamic efficiency research from the United States, as well as conducting an interview with an aviation engineer in Vietnam. The data collected from the two sources were compared by looking at patterns in the variables from the literature review of prior sources and the interview. The findings of the study indicated that as the rainfall intensity increased, the efficiency of the aircraft decreased. Although changes in the shape of the airfoil had a small effect in reducing the aerodynamic efficiency of the aircraft because of the rain, surface factors had a larger influence than changes in shape. Hydrophobic coatings had a high potential in improving efficiency, but had not yet been experimented with by many researchers. The interview's responses, however, indicated that most engineers in Vietnam preferred operational changes rather than changes in the aircraft's design because the costs of the changes would be too much compared to the efficiency gained by the changes. Overall, this study shows that rain does indeed have a negative influence on the efficiency of aircraft, and although changes in the aircraft's design could increase efficiency, it is not yet ready for commercial use.

INTRODUCTION

In recent years, air transport has been playing an increasingly important role in Vietnam's economic development. However, Vietnam's tropical climate poses a significant challenge for aircraft performance. Vietnam experiences heavy rainfalls during the monsoon season every year. In 2025 alone, nearly 1,400 domestic flights were cancelled within the first nine months of the year. Most of these cancellations were due to weather conditions, such as heavy rain and strong winds. Although some of these cancellations are necessary for safety reasons, not all cancellations were just because of safety. Economic factors also play a key role, particularly for low-cost carriers. Low-cost carriers have stricter policies about profit than traditional carriers, so any reduction in efficiency, for example, increased drag and fuel consumption during heavy rainfalls, may make certain flights not profitable. Because of this, they may opt to cancel or delay flights, not because they are unsafe, but because operating them would lead to added costs. These cancellations not only affect customer satisfaction due to flight delays but may also impose even more costs on the carriers themselves, highlighting the need for improved aircraft performance in wet atmospheric conditions. Beyond delays and cancellations, heavy rainfall also poses other concerns in terms of aviation safety, fuel efficiency, and environmental effects. If the aircraft experiences an increase in drag due to rain, there will be a need to increase the thrust and fuel consumption of the engines in order for the aircraft to fly stably. This could then lead to an increase in fuel consumption, which could then lead to an increase in greenhouse gas emissions. In a developing aviation industry like Vietnam, where there is an increasing volume of passenger traffic, a small source of inefficiency like this could lead to high economic and environmental costs.

One important factor influencing aircraft performance in rain is aerodynamics. Previous aerospace research shows that rainfall can affect the aerodynamic behaviour of aircraft surfaces by shifting airflow characteristics around wing structures (Vijayakumar et al., 2024). Many studies have shown that water droplets can increase surface roughness,

reduce lift, and increase drag (Chatterjee et al., 2018; Sor et al., 2017). These changes reduce overall aerodynamic efficiency and may require higher fuel consumption or operational challenges like cancellations or delays. A key study by Patel et al. (2022) demonstrated that increasing rain intensity significantly increases drag and reduces lift in aerodynamic simulations, providing a foundation for understanding performance loss in wet conditions. International research in aircraft design has therefore explored methods such as modified airfoil geometries, surface coatings, and hydrophobic treatments to control performance loss in wet environments ("New Coatings Process," 2012). While these approaches have been studied internationally, there has been limited research that has focused on how such aerodynamic design considerations could be applied specifically to tropical aviation environments like Vietnam, where heavy rainfall occurs frequently, even for a whole season

Therefore, understanding how aircraft aerodynamic design can be optimized for Vietnam's rainy conditions is important for improving efficiency and reliability in its aviation sector. This study investigates how aerodynamic design strategies could reduce performance losses caused by rainfall and improve aircraft efficiency under Vietnam's conditions.

Our Central research question:
How does rainfall intensity affect the aerodynamic efficiency of fixed-wing aircraft, and how can design adaptations improve flight performance and fuel efficiency under tropical rain conditions in Vietnam?

Null Hypothesis (H_0): Rainfall conditions do not significantly affect aircraft aerodynamic efficiency, and design modifications will not meaningfully improve performance.

Alternative Hypothesis (H_a): Rainfall conditions reduce aerodynamic efficiency, and optimized aerodynamic design features, such as modified airfoils or other treatments, can improve aircraft performance in wet conditions.

Aerodynamic efficiency refers to the ability of an aircraft to generate lift while minimizing drag during flight. An airfoil is the cross-sectional shape of a wing that determines how air flows around it and therefore influences lift and drag. Lift is the upward aerodynamic force that allows an aircraft to stay flying, while drag is the resistance force that opposes motion through the air.

By examining existing aerospace research and combining it with insights from the Vietnamese aviation industry, this study aims to identify aerodynamic design strategies that could improve aircraft efficiency in Vietnam's rainy climate.

METHODOLOGY

Study Design

This investigation uses a two-method design, combining a detailed literature review with an interview of a local aviation engineer.

This approach addresses the research question well because each method covers a part of the answer to our research question. The literature analysis will help us understand how rain causes aerodynamic inefficiency, including lift reduction, drag increase, and how we can adjust parts of an airplane to adapt to rain, based on research done in the United States. However, these results are usually found from controlled experiments or aerodynamic simulations, which may not fully reflect the environmental and operational complexity of Vietnam.

Therefore, we will conduct an interview with local engineers in the airline industry to provide insight into a context more fit to our study. These interviews are essential for narrowing the investigation to Vietnam because they reveal

how aerodynamic effects actually appear in operations within a tropical climate. This includes how heavy rainfall interacts with current local flight procedures, aircraft usage, maintenance, and material availability. We can also look at Infrastructure and operational constraints that new designs must avoid.

Without this interview part, the study would be too broad and theoretical, without the local perspective required to be realistic with our design adaptations. The interview allows the research to move from just simulations to make it more realistic, ensuring that our conclusions are directly relevant and applicable to Vietnam's environment.

This integration of two parts strengthens the reliability of our findings and allows the research to produce conclusions that are both scientifically supported and could actually be operationally adapted in Vietnam's aviation industry.

Participants and Data Sources

The sample consists of two main data sources:

1. **Literature Sources**
   We looked at academic and industry research papers, and those were chosen from databases such as Gale and university publications and papers. Sources were chosen based on relevance to aerodynamic performance in wet conditions, with a focus on measurable variables such as lift coefficient, drag coefficient, and stall angle.
2. **Interview Participants**
   Using relations, our study contacted aviation professionals in local airlines as interview participants. These professionals were grouped into: Flight crew, Maintenance engineers, and Design specialists.

   The professionals were chosen based on their experience operating in Vietnam's tropical aviation environment. However, due to participant availability, flight crew were excluded after selection. The final interview sample consisted of one aviation engineer representing a team of three lead engineers (n = 1). While the insights reflect broader engineering practices discussed within the team, only one individual participant was directly interviewed.
3. **Materials**
   The study used these materials and tools:
   Literature databases (Gale and university papers)
   Structured interview question sets
   Google Sheets for organizing data and patterns
   Table for organizing responses from engineers

Variables

- Independent Variables (IV): Environmental conditions and Aerodynamic design adaptations and changes (Surface coatings (hydrophobic vs standard), wing geometry, airfoil shape, high-lift device configuration, aircraft body design characteristics)
- Dependent Variables (DV):
  - Lift performance (CL changes)
  - Drag increase (CD changes)
  - Stall angle variation
  - Operational effects reported by engineers
  - Maintenance effects reported by engineers
- Controlled Variables:
  - Use of similar commercial aircraft categories
  - Standardized questions for all engineers
- Confounding Variables:
  - Rain variability
  - Aircraft differences
  - Regional climate variation

Procedure

This study followed the following five-step procedure:

1. **Literature Review**
   Relevant aerodynamic studies are found from academic databases such as Gale and university research papers. The selection focuses on studies on the effects of rain on aircraft performance, as well as papers looking at aircraft design vs. performance in rain.

   These are some variables our study looked at in the papers:
   Independent variables:
   - Rain condition (wet vs. dry)
   - Rain intensity (liquid water content (LWC), rainfall rate)
   - Aerodynamic design characteristics (airfoil shape, surface roughness, geometry variations)

   Dependent variables:
   - Lift coefficient (CL and CLmax changes)
   - Drag coefficient (CD changes)
   - Stall angle variation
   - Lift-to-drag ratio (efficiency indicator)

   Each data point includes units (% change, coefficient values), test conditions, and model type (CFD, wind tunnel, experimental setup). This is used so that results from different studies can be easily compared.
2. **Interview Data Collection**
   Our study contacted and prepared questions for our interview with the engineer. The same question set is used for all interviewees to ensure consistency and reduce bias.
   The questions are designed to gather insights across three key areas:
   - Operational effects (Flight operations, delays & cancellations)
   - Maintenance considerations (material availability, aircraft type)
   - Design limitations and adaptations (features that perform better or worse in rain)

   The interviews are conducted both in person and through digital calls. Responses from engineers are recorded in a table, with notes taken during each interview to ensure accuracy.
3. **Data Analysis and Synthesis**
   All collected data from both the literature review and the interview are organized in spreadsheets. Literature data is arranged by the variables mentioned above, while responses from engineers during the interview are sorted into the categories mentioned above. Each line includes contextual information such as aircraft type (if mentioned), rain intensity, and the role of the interview participant. Raw responses are kept separate from interpreted summaries to maintain transparency (for interviews). A comparative analysis is then conducted by comparing the information from the literature with the responses from the engineers. Patterns are considered significant if they are supported by multiple literature sources and are consistent with the interview findings. Literature data is compared using reported percentage changes in lift and drag, while interview data is grouped into themes such as operational, maintenance, and design effects.
4. **Design Adaptations Development**
   Based on the compared findings, we then start developing potential aerodynamic design adaptations. These proposals are specifically tailored to be realistically adaptable to Vietnam's tropical environment and operational constraints.
   Suggested adaptations are grouped into categories such as:
   - Surface treatments (hydrophobic coatings)
   - Wing geometry modifications
   - Operational adjustments for wet conditions

Each proposed adaptation has to be supported by both aerodynamic theory and insights from engineers, meaning that recommendations are analyzed from both sides of the literature and our interviewees.

Ethics

- Informed consent was obtained from all interview participants
- Participation of interview participants is voluntary
- Responses from interview participants are anonymous
- No sensitive information is collected
- Data is securely stored and only accessible to the researcher and supervisor.

Statistical/Analysis Plan

For the literature review, quantitative data are analyzed by comparing reported changes in aerodynamic variables such as drag (CD) and lift (CL) across multiple studies. Where possible, ranges of values or percentages are identified to determine the overall magnitude of rainfall effects on aerodynamic efficiency.

For the interview, responses are analyzed using category analysis, where answers are grouped into key categories that we have mentioned.

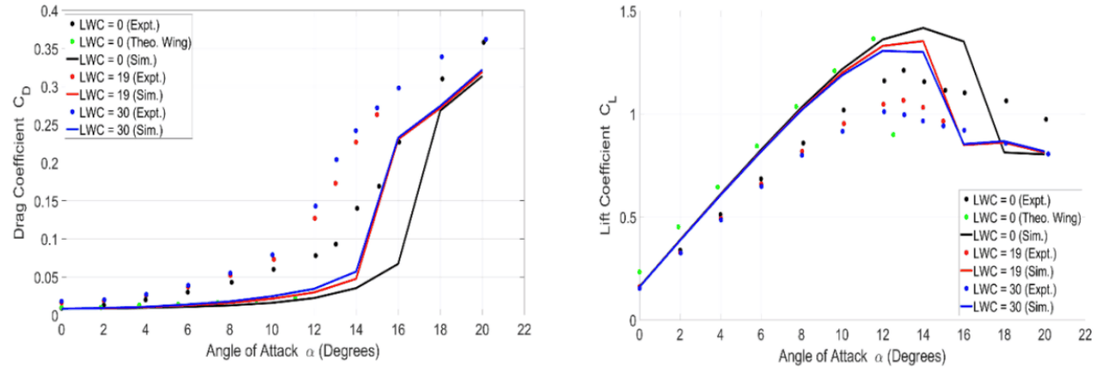
Findings are then compared across both data sources. A pattern is considered significant when it is supported by multiple literature sources and is consistent with the interview findings.

RESULTS

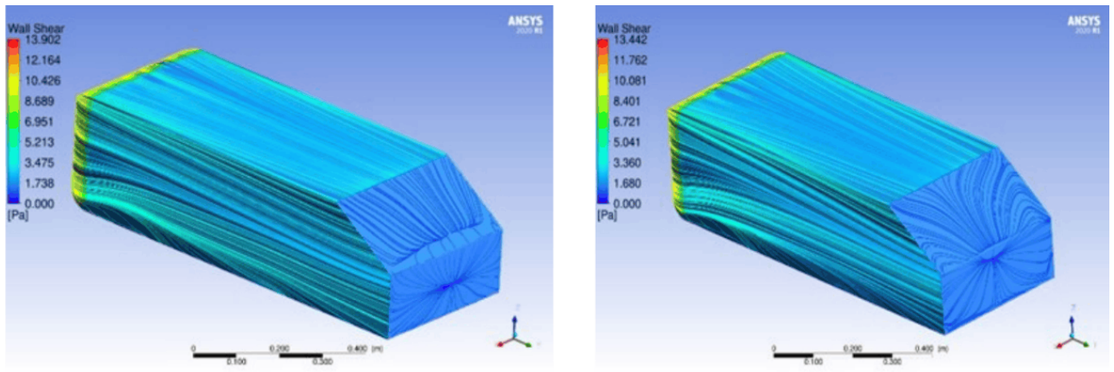
Effects of Rain Intensity and Aerodynamic Design

In our literature review, our study found that both rain intensity and aerodynamic design influenced aircraft performance, although rain intensity was the more significant factor in the cause of efficiency loss. As rain intensity increases, aerodynamic degradation becomes more severe across all models.

Studies using liquid water content (LWC) as a measure of rain intensity showed that drag increases while lift decreases as LWC increases, especially at higher angles of attack (the angle at which the aircraft meets the droplet). In fixed-wing airfoil simulations, heavy rain conditions caused drag increases of around 29-33% and lift reductions of 11-14%, resulting in overall performance losses of over 40%, as reported by Patel et al. (2022) (Figure 1). At higher rain intensities, other simulation studies reported that drag could double or increase by more than 150%. A non-linear negative relationship between rain intensity and aerodynamic efficiency was found.



(a) Drag coefficient **(b) Lift coefficient**



(a) LWC = 19 g/m³ **(b) LWC = 30 g/m³**

Figure 1: *Variation of drag coefficient (a) and lift coefficient (b) with angle of attack under different rain intensities, represented by liquid water content (LWC = 0, 19, and 30 g/m³). Results show that increasing rain intensity leads to higher drag and reduced lift, particularly at higher angles of attack, indicating significant aerodynamic performance degradation under wet conditions. Adapted from Patel et al. (2022).*

To better synthesize quantitative findings across multiple studies, Table 1 summarizes reported changes in lift and drag under different rainfall conditions.

Study / Model	Rain Intensity Measure	Drag Change (C_D)	Lift Change (C_L)	Key Observation
Patel et al. (2022)	LWC = 19–30 g/m³	+29% to +33%	-11% to -14%	Significant efficiency loss at higher angles of attack
CFD Airfoil Studies	Moderate to heavy rain	+30% to >100%	-10% to -15%	Non-linear increase in drag with intensity
High-intensity studies	High rainfall conditions	Up to +150% or more	Decrease (varies)	Extreme drag increase in severe rain
UAV simulations	Simulated rain conditions	Increased drag	Reduced lift (>10%)	Lift-to-drag ratio decreased by >25%
Multi-element wings	Wet surface conditions	Increased drag	Larger C_L reduction	More sensitive to rain effects

Table 1: *Summary of aerodynamic performance changes under rainfall conditions (adapted from reviewed literature)*

Our study found that aerodynamic design does influence these effects from rain, but does not fully help the drag and lift issues from the rainfall. Comparative CFD studies of different airfoil geometries showed that performance values only differed slightly between designs. The relative degradation due to rain was still very similar. For example, the NACA 2415 and 23012 airfoils were very similar in overall performance losses in rain, even when they had differences in their shape and geometry.

Another study with other complex aerodynamic configurations showed slightly similar results. High-lift and multi-element wing systems showed even larger reductions in lift and greater decreases in stall angle under rain conditions. In UAV simulations, lift reductions became more significant at higher angles of attack, while lift-to-drag ratios decreased by over 25%.

Across the literature reviewed, drag increases generally ranged from approximately 29% to over 100%, while lift reductions ranged from approximately 10% to 15%, depending on rain intensity and model type. This shows a consistent trend of significant aerodynamic efficiency loss under rainy conditions.

Surface interactions were actually found to be a bigger factor in airplane design vs. performance. Experimental and computational studies showed that water droplets deform and interact with airflow differently depending on their position on the airfoil. These interactions disturb the boundary layer and change pressure distribution, increasing drag and reducing lift. Studies on surface roughness showed that even small changes to surface condition can significantly increase aerodynamic inefficiency, with drag increases ranging from doubling to several times the baseline values.

The study followed that with research into hydrophobic and advanced surface coatings that suggest reducing water adhesion and limiting continuous water film formation can control boundary-layer disruption, reducing drag. Compared to geometric design adjustments, these coatings directly target the surface interaction with water, which has a greater impact on the aerodynamic issue with rainfall and loss of efficiency. Therefore, the hydrophobic coatings give a good idea for improving aerodynamic efficiency in rain conditions like Vietnam in our study.

Overall, the results show that while aerodynamic design affects the magnitude and sensitivity of performance loss, all types of airfoil designs experience consistent inefficiency as rain intensity increases. The interaction between rain and surface conditions becomes a bigger factor in influencing aerodynamic performance.

Operational Effects Reported by Aviation Engineers

Our study then collected interview responses from one aviation engineer with experience in Vietnam Airlines operations (n = 1), representing a team of three lead engineers. He first reported to us the operational impacts of heavy rain across different phases of flight.

During takeoff and climb, he stated that the most significant effects were observed. These included reduced engine performance due to water ingestion, increased aerodynamic drag, and longer takeoff distances resulting from wet runway conditions. He also stated there is reduced visibility as another contributing challenge, but this is just mainly for pilots, not really an aerodynamic challenge.

During the cruise phase, he mentioned that minimal impact was reported, as aircraft typically operate above regions of heavy rainfall. As a result, aerodynamic impact due to rain is reduced at cruising altitude.

During approach and landing, however, the Vietnam Airlines Engineer stated that several performance and safety-related effects were identified. These included increased approach speed (VAPP), reduced braking effectiveness on wet runways, decreased visibility, and the potential presence of windshear near the runway.

Observed Changes in Performance Indicators

The engineer reported that rotation distance increases, acceleration rate slightly decreases, and approach speed (VAPP) increases by approximately 2–5 knots under rainy conditions.

Operational Constraints and Decision Factors

The engineer then explained the decision-making system with several constraints that influence operational decision-making, like delays and cancellations during heavy rain, such as:

- Rosswind limits
- Windshear advisories
- Reduced braking action
- Increased required landing distance
- Weather radar limitations
- Aircraft performance limitations and regulatory constraints

The engineer also stated that there is never a threshold for a cancellation or a delay for each of these reasons, and the decision is made by the pilot.

Maintenance and System-Level Effects

In terms of maintenance, the engineer's responses indicated that heavy rain and humid conditions primarily affect aircraft systems through increased exposure to moisture. Some of the key effects include the increased risk of water ingress and corrosion, which reduces the reliability of certain aircraft components.

In terms of systems, the ones identified by the Vietnam Airlines engineer as sensitive include flight control systems, landing gear systems, structural components, and avionics systems. Additional inspection procedures, particularly for avionics, are implemented to maintain reliability during the rainy season.

Aerodynamic Design Observations

In addition, our interview indicated that aircraft design plays a role in performance under rainy conditions. According to our engineer, wide-body aircraft such as the A350 and B787 were observed based on airline data to perform more effectively in heavy rain because of their larger wing sweep and more stable aerodynamic structure.

However, several aerodynamic limitations were also stated. These are the same noticeable reductions in maximum lift coefficient (CLmax) and lift-to-drag ratio under wet conditions in our literature review. Multi-element high-lift devices, such as flaps and slats, were reported to become more sensitive when surfaces are wet. The formation of thin water films was also noted to change the pressure distribution across the wing surface.

Engineer's Perspective on Design Changes

However, a finding from the interview data is that, although clear aerodynamic and operational impacts were suggested to the Vietnam Airlines Engineer, there was limited support from the local engineers for major design modifications specifically targeting rain conditions.

When asked about potential design improvements, like hydrophobic coatings, modified leading-edge geometry, or surface texturing, the engineer indicated that no specific design changes were prioritized. Instead, he emphasized that some factors could be improved, not relating to design. For example, he stated that we can still rely on existing aircraft designs, which are already optimized for a wide range of operating conditions, but we can improve operational procedures and weather forecasting reliability to be more accurate with flight predictions, instead of having to change aircraft structure.

This perspective suggests that current aircraft designs are still considered usable and that efficiency losses in rain are treated as common issues and can be dealt with operationally.

Summary of Observed Patterns

Across both the literature review and interview responses, these are the trends that were found:

- Rain increases drag and reduces lift across all aerodynamic models
- Higher rain intensity leads to greater efficiency loss
- Aircraft geometry influences sensitivity, not efficiency, to rain effects
- Operational impacts include increased speeds, reduced stability, and longer takeoff and landing distances
- Surface interaction with water is a primary factor in performance degradation
- Different coatings look to have the most impact on performance improvement
- However, there is limited support for major design modifications, with a preference for operational and procedural improvements.

DATA ANALYSIS

In terms of the first part of our investigation with the literature review, we have found that rain indeed does reduce aerodynamic efficiency by increasing drag and decreasing lift. In simple terms, aircraft become less efficient in heavy rain because water disrupts the smooth airflow over the wing. This disruption affects the boundary layer and pressure distribution, which forces the aircraft to use more thrust or fuel to maintain the same level of performance, which increases costs that we were talking about.

We have also found a strong relationship across all sources is that rain intensity directly increases performance loss. As rain becomes heavier, drag increases significantly while lift decreases. In several studies in our literature review,

drag increased by around 30 percent in moderate heavy rain and could even double under higher rain intensities. Meanwhile, lift decreased by around 10 to 15 percent, and stall angle was reduced. These changes occurred consistently across different types of simulations and experiments in our different sources.

However, when looking at sources trying to adapt to these conditions and increase performance by altering the aerodynamic design of the plane, the design was actually found to play a limited role in improving the plane's performance in rain. Different airfoil shapes and configurations showed similar overall performance losses, even when their baseline efficiencies were different. These results show that systems designed to maximize lift in normal conditions are also more vulnerable to disruption when exposed to water droplets and surface films.

And these findings are consistent with prior research in aerodynamics. Studies on icing and surface contamination show similar patterns of lift reduction and drag increase. This supports the idea that the main issue is not only rain itself, but the interaction between water and the aircraft's surface. Droplet deformation, water film formation, and increased surface roughness all contribute to airflow disruption. Because these effects occur at the surface level, they affect all aerodynamic designs similarly.

Our study then looked at solutions directly at surface-type design changes, which also shows that improving performance in rain is more effective when focusing on those changes instead of overall aircraft shape. Hydrophobic coatings and surface treatments can reduce water adhesion and limit the formation of continuous water films, which are a major cause of airflow disruption. Compared to aerodynamic changes, these approaches directly target the system that causes performance loss and therefore bring a greater impact. However, these technologies are still under development and have not yet been widely implemented in commercial aircraft.

In terms of our interview, the application section of our study, the impact of these rain effects is shown and confirmed to be significant in commercial flights. Increased drag and reduced lift lead to longer takeoff distances, higher approach speeds, and reduced stability. This is supported by the Vietnam Airlines Engineer with airline data, showing increases in approach speed of around 2 to 5 knots and reduced acceleration and stability. These changes affect fuel consumption and safety margins. According to the engineer, even these relatively small percentage changes in aerodynamic performance can result in a lot of added costs for airlines.

However, words from the engineer suggest that applying these design adaptations in Vietnam's context would not be realistic. Engineers emphasized that aircraft are already optimized for safety and are still operating efficiently in a wide range of conditions, and that rain-related efficiency losses are accepted as operational constraints. Since heavy rain mainly affects limited phases of flight, the overall efficiency gains from implementing solutions such as hydrophobic coatings do not outweigh the cost and maintenance complexity if we were to apply these changes.

Overall, the interview responses from the engineer show us that rainfall aerodynamic losses should not be addressed with major design changes in current aircraft, as these effects can be managed effectively through operational practices. However, based on the first section of our study, the literature review, if design modifications were to be considered, they would be most effective when focused on reducing surface interaction with water, such as through hydrophobic coatings or surface treatments, rather than aerodynamic shape optimization. However, these conclusions are limited by the small interview sample size (n = 1) and the lack of locally conducted aerodynamic simulations specific to Vietnam's tropical conditions. While the literature provides strong theoretical support, the practical conclusions should be generalized with caution.

CONCLUSION

This study aimed to determine how aerodynamic design adaptations could reduce performance loss and improve aircraft efficiency under heavy rain conditions in Vietnam.

We partially rejected the null hypothesis. The results show that indeed rain consistently increases drag and reduces lift. However, the results also showed that aerodynamic design changes, such as modifying airfoil geometry, have a very low impact. But certain adaptations outside of aerodynamics, like surface design, particularly those on surface interactions such as hydrophobic coatings, do have a great potential to reduce aerodynamic degradation.

More importantly, however, the interview with one engineer indicated that these potential improvements are not prioritized due to cost-benefit considerations within that operational context. According to our interviewed engineer, current aircraft designs are already optimized for safety and performance across a wide range of conditions, including heavy rain. Efficiency losses during rain are accepted as part of operational constraints rather than problems requiring a major redesign. Also, rain affects only certain phases of flight (takeoff, climb, landing), meaning that the overall benefit of design alterations would be small with very high costs to implement them.

So this study will not provide a full design recommendation, as our results suggest implementing solutions such as hydrophobic coatings (our hypothetical and theoretical design recommendation) when considering factors such as cost, durability in tropical climates, maintenance requirements, and relatively small overall efficiency gains is not optimal. Instead, the aviation industry in Vietnam focuses on operational strategies, including improved weather forecasting and stricter safety margins.

If these design adaptations were to be implemented in the future, they would likely need to focus on surface-level improvements that directly reduce water interaction. However, these would need to be carefully researched, tested, and simulated. It needs to be tested and ensure long-term durability and compatibility with existing aircraft systems in order to be actually implemented in commercial planes.

EVALUATION/LIMITATIONS

Some strengths of our study are, first, our use of the two-method approach, combining multiple peer-reviewed aerodynamic studies with interview responses from local professionals. This allowed us to cross-compare between simulations and real experience. Patterns were analyzed across all sources, making it easy to compare and strengthen the overall conclusions as we look at multiple sources getting similar results, even if the conclusion is not practical, at least we are informed that. The use of structured interview questions also ensured consistency in responses, reducing variability and bias in qualitative data.

However, there are several limitations that affect the strength of the conclusions. First, the study relies heavily on secondary data from simulations and experiments that use simplified models such as airfoils or UAVs. These may not fully represent the complexity of full aircraft systems in real environments. Another limitation is that our interview sample was limited in size and scope, with responses only reflecting a specific operational context. This may introduce bias and limit generalizability to other airlines or regions. A third limitation was the unavailability of simulations for hydrophobic coatings or even aerodynamic shapes and designs. We wanted to conduct a simulation on how the hydrophobic coatings could work, but those require advanced technology and systems, unavailable to a high school lab. Additionally, during the literature review, limited peer-reviewed studies were found specifically investigating hydrophobic coating performance under rainfall conditions, indicating a broader research gap beyond just laboratory constraints. If this study could be replicated, it would be good to add simulations on top of the literature review, along with a bigger interviewee size. Finally, most of the literature data were derived from international studies, primarily conducted in non-tropical environments, which may not fully represent the atmospheric conditions specific to Vietnam's climate.

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Research on biodegradable fabrics and their possibility in transforming fast fashion sustainability

INTRODUCTION

Background on Fast Fashion and Environmental Impact

Fast fashion refers to the rapid production of inexpensive clothing that mirrors current trends, encouraging frequent consumption and disposal. While economically efficient, this model contributes significantly to environmental degradation, including high carbon emissions, excessive water use, and the accumulation of textile waste. Polyester, the most widely used fiber in global production, is a synthetic material derived from petroleum and is non-biodegradable, allowing it to persist in the environment for decades or even centuries while contributing to microplastic pollution.

Natural vs Synthetic Fabrics

In contrast, existing research suggests that natural fibers such as cotton and linen offer potential solutions due to their biodegradability and reduced long-term environmental persistence. Unlike polyester, these materials are composed primarily of cellulose, allowing them to decompose through microbial activity in composting conditions. Life cycle assessments indicate that while polyester has lower immediate production costs and greater durability, it contributes significantly more to long-term environmental harm due to its resistance to degradation.

Limitations and Trade-offs

However, prior studies also highlight important trade-offs. Cotton production is highly water-intensive, and linen, although generally more environmentally efficient, requires labor-intensive processing and higher production costs. These limitations create a tension between environmental sustainability and economic feasibility within the fast fashion industry.

Study Aim and Significance

This study investigates to what extent natural biodegradable fabrics such as cotton and linen can reduce the environmental impact of fast fashion compared to polyester, and what limitations affect their practical adoption. To address this, a four-week controlled composting experiment was conducted using equal-sized samples of cotton, linen, and polyester, with polyester serving as a non-biodegradable control. All materials were placed in a balanced compost system containing carbon and nitrogen inputs while maintaining consistent moisture and aeration. Decomposition was measured through weekly observations of structural breakdown using a standardized decomposition scoring system and supported by qualitative assessments of material degradation.

The analysis followed a comparative approach, using a time-based decomposition model to evaluate differences in degradation rates between fabric types. This research is significant because fast fashion produces large amounts of non-biodegradable textile waste, particularly from polyester, which persists in the environment for decades. By comparing cotton and linen as biodegradable alternatives against polyester, this study highlights both the environmental advantages of natural fibers and their practical limitations. Understanding these trade-offs provides insight into how the fashion industry can reduce environmental harm while remaining economically viable.

Research Question

The research question guiding this study is: To what extent can natural biodegradable fabrics such as cotton and linen reduce the environmental impact of fast fashion compared to polyester, and what economic and practical challenges limit their widespread adoption?

Hypothesis

It is hypothesized that under controlled composting conditions over four weeks, cotton will exhibit a measurable rate of decomposition due to microbial breakdown of cellulose, linen will also decompose but at a slightly slower rate due to its stronger fiber structure, and polyester will show no significant decomposition, reinforcing its classification as a non-biodegradable material.

METHODOLOGY

Study Design

This study was a controlled experiment comparing the rate of decomposition of cotton, linen fabrics and polyester fabrics in a composting environment. The independent variable was the type of fabric, while the dependent variable was the degree of decomposition over time. Both materials were composted under the same environmental conditions to ensure a fair comparison.

Sample Description

The sample consisted of three types of natural fabrics: 100% cotton, 100% linen and 100% polyester. Each fabric was cut into equal-sized pieces (e.g., 5 cm × 5 cm). A total of 6 samples were used. No samples were excluded during the experiment.

Materials and Instruments

- Plastic compost container with lid **(30 L capacity)** with **around 15 holes (≈ 0.5–1 cm diameter)** for aeration and drainage
- Scissors (for cutting compost materials and fabric samples into smaller pieces)

Compost Base Materials

- Organic soil or compost **(5 kg)**

Green Materials (Nitrogen Sources, ~2 kg total)

- Fruit and vegetable scraps (cut into **5 cm pieces**)
- Used tea bags **(2 bags per week)**
- Crushed eggshells **(2 eggs per week)**
- Coffee grounds **(100 g per week)**
- Fresh grass clippings **(200 g)**

Brown Materials (Carbon Sources, ~2 kg total)

- Dried leaves **(200 gram)**
- Shredded paper scraps **(200 g)**
- Cardboard pieces **(cut into small strips, 200 g)**
- Toilet paper roll tubes **(2 rolls, cut into pieces)**
- Wood chips **(200 g)**

Fabric Samples
- 100% cotton fabric **(2 pieces, each 5 cm × 5 cm)**
- 100% linen fabric **(2 pieces, each 5 cm × 5 cm)**
- 100% Polyester fabric **(2 pieces, each 5 cm × 5 cm)**

Other Materials
- Water (**100 mL every 2–3 days**, adjusted as needed)
- Gloves (1 pair, for safe handling)
- Ruler (**30 cm**, optional for measurement)
- Notebook for observation recalling

Variables

Independent Variable (IV)

The type of fabric used: **100% cotton vs 100% linen vs 100% Polyester**

Dependent Variable (DV)
- Fabric texture (softness, brittleness)
- Structural integrity (tearing, holes, fragmentation)
- Color changes (light to dark brown)

Controlled Variables
- Size of fabric samples **(5 cm × 5 cm)**
- Number of samples **(2 per fabric type)**
- Compost composition (same ratio of green and brown materials)
- Container size **(30 L)** and setup
- Depth of burial in compost
- Moisture levels **(100 mL water every 2–3 days)**
- Duration of experiment **(4 weeks)**
- Environmental conditions (same location, temperature, and light exposure)

Confounding Variables
- Uneven distribution of microorganisms within the compost
- Slight variations in moisture or airflow within different areas of the container
- Differences in fabric weave density or thickness

Procedure

1. Prepared a **30 L plastic compost container** by creating ~15 holes (0.5–1 cm diameter) around the sides and bottom for aeration and drainage.
2. Added **~5 kg of organic soil/compost** as a base layer to introduce microorganisms.
3. Prepared compost materials:
   - Green materials (~2 kg total): fruit/vegetable scraps (2–3 cm pieces), tea bags, eggshells, coffee grounds, grass
   - Brown materials (~2 kg total): dried leaves, shredded paper, cardboard, toilet roll tubes, wood chips
4. Assemble the compost by layering green and brown materials evenly, then lightly mixing to promote aeration.
5. Cut 1**00% cotton, linen and polyester fabrics into equal sizes (5 cm × 5 cm)**, preparing **2 samples of each fabric type.**
6. Buried all fabric samples at the **same depth and evenly spaced positions** within the compost.
7. Covered the fabrics completely with compost material and closed the container with a lid.
8. Maintained moisture by adding **100 mL of water every 2–3 days**, ensuring the compost remained damp but not waterlogged.
9. Mix the compost **once per week** to maintain oxygen flow and support microbial activity.

10. Conducted weekly **observations over 4 weeks**, recording:
    - Changes in texture, color, and structure
    - Level of decomposition
11. Compared the decomposition of cotton and linen samples at the end of the experiment.

Ethics

This study did not involve any participants. Therefore, no ethical concerns such as consent, anonymity, or confidentiality were required.

All data collected (observations and images) were used solely for academic purposes and stored securely by the researcher.

Data Analysis Plan

Data was analyzed using **qualitative comparative analysis**, as the study focused on observable physical changes rather than numerical measurements.

- Weekly observations were recorded and compared between cotton, linen and polyester samples
- Patterns in decomposition (e.g., rate of fraying, fragmentation, and discoloration) were identified
- No formal statistical tests were conducted due to the descriptive nature of the data. Therefore, a significance threshold ($\alpha = 0.05$) was not applied.
- However, consistent observation methods and controlled conditions were used to ensure reliability and validity of the results.

RESULTS

The results of the 4-week composting experiment comparing cotton vs linen fabrics vs polyester fabric are presented below using tables an d graphical representations.

Decomposition Score Scale

Mean = overall trend
Range = consistency
Median = typical sample

Mean (Variation in Decomposition):
0 = No change
1 = Slight softening/discoloration
2 = Fraying/weakening
3 = Tearing/holes forming
4 = Partial disintegration
5 = Near complete decomposition

Range (Variation in Decomposition)
0–0 = All samples identical (no variation)
0–1 = Very minimal variation
1–2 = Low variation
2–3 = Moderate variation between samples
3–4 = High variation
4–5 = Very high variation (samples decomposed at very different rates)

Median (Typical Decomposition Level)
0 = No change
1 = Slight softening/discoloration
2 = Fraying/weakening
3 = Tearing/holes forming
4 = Partial disintegration
5 = Near complete decomposition

Week	Fabric	Mean Score	Range	Median	Key Observations
W1	Cotton	1.0	1-1	1.0	Slight softening observed. Fabric absorbed moisture but remained structurally intact with minimal discoloration.
W1	Linen	0.8	0-1	1.0	Very minimal change. Fabric remained firm with slight dampness and almost no visible degradation.
W1	Polyester	0	0-0	0	No visible change. Fabric remained completely intact with no softening, discoloration, or structural alteration.
W2	Cotton	2.5	2-3	2.5	Noticeable fraying at edges. Fabric weakened and showed early signs of structural breakdown and discoloration.
W2	Linen	2.0	2-2	2.0	Moderate softening and slight fraying. Structure remained more intact compared to cotton.
W2	Polyester	0	0-0	0	No observable decomposition. Fabric remained unchanged with no fraying or weakening.
W3	Cotton	3.8	3-4	4.0	Significant tearing and thinning observed. Some samples developed small holes and began fragmenting.
W3	Linen	3.0	3-3	3.0	Visible weakening and minor tearing. Fabric still held its overall shape with fewer holes than cotton.
W3	Polyester	0	0-0	0	No structural changes observed. Fabric remained intact; slight dirt accumulation may be present but no decomposition.
W4	Cotton	4.5	4-5	5.0	Advanced decomposition. Fabric partially disintegrated with fragments mixing into compost. The texture became soft and crumbly.
W4	Linen	3.8	3-4	4.0	Partial breakdown observed. Fabric showed tearing and thinning but retained more structure than cotton.
W4	Polyester	0	0-0	0	Minimal visible change. Fabric remained structurally intact; slight discoloration or surface wear observed but no true decomposition.

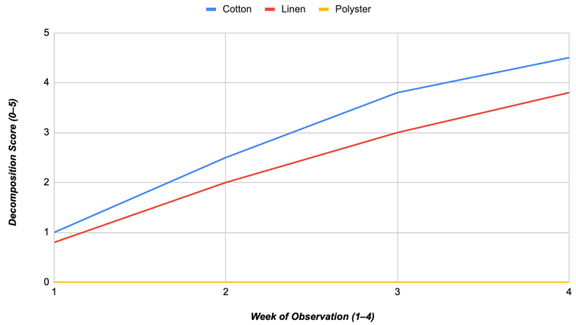
Table 1: *Descriptive Statistics*

Observational Findings

Cotton showed the highest decomposition scores over time, while polyester remained unchanged. Linen showed moderate decomposition between the two.

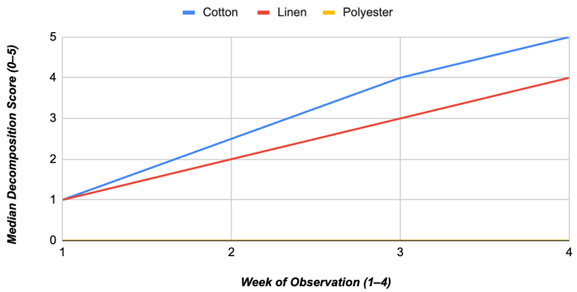
Graphical Representation of Mean (Figure 1)

Mean Decomposition Scores of Cotton, Linen, and Polyester Fabrics Over a 4-Week Composting Period



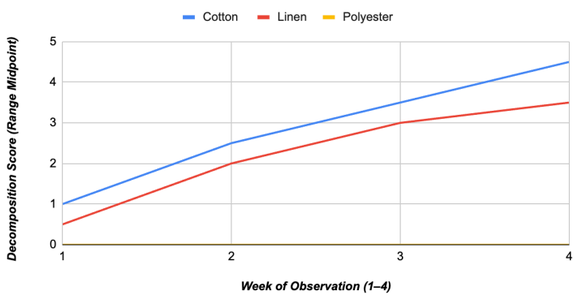
This line graph shows the mean decomposition scores of cotton, linen, and polyester fabrics over a four-week composting period. Cotton demonstrates the fastest rate of decomposition, followed by linen, while polyester remains at a constant score of zero, indicating no significant breakdown.

Median Decomposition Scores of Cotton, Linen, and Polyester Fabrics Over Time



This graph illustrates the range of decomposition scores for each fabric type across four weeks, indicating the level of variation between samples. Cotton and linen show increasing variability over time, while polyester maintains a range of 0–0, reflecting no variation or decomposition among samples.

Variation in Decomposition Scores (Range Midpoints) of Fabrics Over 4 Weeks



This graph presents the median decomposition scores of cotton, linen, and polyester fabrics over the experimental period, representing the typical level of decomposition. Cotton shows the highest median progression, linen follows a slower trend, and polyester remains unchanged at zero throughout the study.

Fabric Type	Raw Material Cost (per kg)	Fabric Cost (per meter)	Key Economic Factors
Polyester	$1.20–$1.50	$0.60–$2.00	Low cost, mass production, high durability
Cotton	$1.80–$2.20	$1.50–$5.00	Water-intensive, moderate cost, price fluctuations
Linen	Higher than cotton	$3.00–$15.00	Labor-intensive, longer processing time, low scalability

Table 2: *Economic Factor Comparison*

Comparison of production and material costs for polyester, cotton, and linen fabrics, highlighting economic factors that influence their adoption in the fast fashion industry.

DATA ANALYSIS/DISCUSSION

Interpretation of Results

The results of this study show clear differences in the rate of decomposition between cotton, linen, and polyester fabrics over the 4-week composting period. In general, cotton exhibited the fastest rate of decomposition, followed by linen, while polyester showed little to no observable change. This indicates that natural fibers decomposed significantly more than synthetic fibers under the same composting conditions.

Trends and Patterns

A strong upward trend was observed in the mean decomposition scores for both cotton and linen over time. Cotton increased from a mean score of 1.0 in Week 1 to 4.5 in Week 4, demonstrating rapid structural breakdown and partial disintegration. Linen also showed a steady increase, rising from 0.8 to 3.8 over the same period, although at a slower rate compared to cotton. In contrast, polyester remained at or near a score of 0 throughout the experiment, with only minimal surface changes observed by Week 4. This pattern suggests a clear distinction between biodegradable and non-biodegradable materials.

The consistency of results was supported by relatively small ranges within each fabric group. Cotton and linen showed moderate variation in later weeks (e.g., ranges of 3–4 or 4–5), reflecting slight differences in how individual samples decomposed. Polyester, however, maintained a near-zero range (0–0 or 0–1), indicating that all samples behaved similarly and showed almost no decomposition. The median values closely aligned with the mean values, suggesting that the data distribution was relatively balanced and not heavily influenced by outliers.

Comparison with Prior Research

These findings are consistent with prior research on textile decomposition. Natural fibers such as cotton and linen are primarily composed of cellulose, which can be broken down by microorganisms in composting environments. Cotton decomposed more rapidly in this study, likely due to its softer and less rigid fiber structure, which allows for easier microbial access. Linen, derived from flax fibers, has a tighter and more durable structure, which may explain its slower rate of breakdown. In contrast, polyester is a synthetic polymer derived from petroleum and is not biodegradable, which aligns with its negligible decomposition observed in this experiment.

Explanation of Variability

No major anomalies were observed in the data. Minor variations between samples may be attributed to uneven distribution of moisture, oxygen, or microorganisms within the compost system. Additionally, slight differences in fabric weave or thickness could have influenced how quickly individual samples decomposed.

Practical Implications

The results highlight the environmental advantages of natural fibers, as cotton and linen decomposed significantly within four weeks, while polyester showed no meaningful breakdown. This suggests that natural fibers can reduce long-term textile waste and environmental persistence.

However, their adoption is constrained by economic factors. As shown in Table 2, polyester is substantially cheaper to produce, with lower raw material and fabric costs, making it highly scalable for mass production. In contrast, cotton has moderate costs but requires significant water input, while linen is the most expensive due to labor-intensive processing and longer production times.

These cost differences create a clear trade-off between environmental sustainability and economic feasibility. As a result, despite their biodegradability, cotton and linen remain less widely used in fast fashion compared to polyester.

CONCLUSION

This study demonstrates that natural biodegradable fabrics such as cotton and linen can significantly reduce the environmental impact of fast fashion compared to polyester, particularly in terms of post-consumer waste and long-term environmental persistence. Over the 4-week composting period, both cotton and linen showed clear decomposition, with cotton degrading more rapidly than linen, while polyester showed no measurable change.

The results support the hypothesis. Cotton exhibited the highest decomposition due to microbial breakdown of cellulose, while linen decomposed at a slower rate due to its stronger fiber structure. As predicted, polyester remained unchanged, confirming its classification as a non-biodegradable material.

However, despite these environmental advantages, economic constraints limit the widespread adoption of natural fibers. As shown in Table 2, polyester remains significantly cheaper and more scalable, whereas cotton and especially linen involve higher production costs and resource demands. Therefore, reducing the environmental impact of fast fashion will require not only material substitution but also systemic changes in production efficiency, consumer behavior, and waste management.

EVALUATION/LIMITATIONS

Strengths

This study demonstrated several strengths that support the reliability and validity of the findings. First, a controlled experimental design was used, where all fabric samples were exposed to the same composting conditions, including consistent moisture levels, compost composition, container size, and duration. This ensured that differences in decomposition were primarily due to the type of fabric, strengthening internal validity.

Additionally, the use of a standardized decomposition scoring system (0–5 scale) allowed for consistent and systematic observations across all samples and time points. Weekly data collection over a fixed 4-week period also provided a clear time-based comparison, allowing trends in decomposition to be identified. The inclusion of polyester as a control group further strengthened the study by providing a clear baseline for non-biodegradable behavior, making the differences between natural and synthetic fibers more meaningful.

Limitations

Despite these strengths, several limitations may have affected the results. One was the use of qualitative measurement methods, as decomposition was assessed visually through changes in texture, structure, and color rather than precise quantitative measurements such as mass loss. This introduces potential observer bias and reduces measurement precision.

Additionally, the composting environment may not have been perfectly uniform. Factors such as uneven distribution of microorganisms, moisture, or oxygen within the container could have influenced decomposition rates. Differences in fabric weave density or thickness, even within the same material type, may have also affected how quickly samples decomposed.

Finally, the short duration of 4 weeks limits the ability to fully assess long-term decomposition, particularly for more durable materials such as linen and especially polyester, which may require months or years to show measurable breakdown.

Improvements / Future Research

Future studies, I would include quantitative measurements, such as mass loss using a precision scale (±0.01 g), would enhance accuracy and reduce subjectivity.

Extending the experimental duration to 8–12 weeks would provide a more complete understanding of decomposition processes. Improved control of environmental conditions, such as monitoring temperature and moisture, would increase consistency.

Further research could also investigate blended fabrics (e.g., cotton-polyester) and compare decomposition across different waste systems (e.g., landfill vs industrial composting) to better reflect real-world conditions.

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How does hyperhidrosis severity influence anxiety levels in adolescents aged 13–18?

ABSTRACT

Hyperhidrosis is a medical condition characterized by excessive sweating beyond what is required for normal thermoregulation. Although it is primarily classified as a physical disorder, growing evidence suggests that it may also have significant psychological and social consequences, particularly during adolescence. Adolescence is a developmental stage in which individuals are highly sensitive to peer perception, social evaluation, and self-image. As a result, conditions that affect physical appearance or bodily control, such as hyperhidrosis, may contribute to increased psychological distress.

This study aimed to investigate the relationship between hyperhidrosis severity and anxiety levels among adolescents aged 13–18. Data was collected through an anonymous online survey using the Hyperhidrosis Disease Severity Scale (HDSS) to measure sweating severity and the Generalized Anxiety Disorder-7 (GAD-7) scale to assess anxiety levels. Descriptive statistics, including means and standard deviations, were calculated, and a Pearson correlation analysis was conducted to evaluate the relationship between the two variables.

The results indicated that 81.25% of participants reported experiencing symptoms of hyperhidrosis, while 75% reported mild to severe anxiety levels. The mean anxiety score was 7.19, indicating mild anxiety, while the mean HDSS score was 2.19, indicating generally mild sweating severity. The correlation analysis revealed a very weak positive relationship ($r \approx 0.11$, $R^2 \approx 0.012$), suggesting that hyperhidrosis severity has minimal influence on anxiety levels within this sample.

Overall, the findings suggest that while hyperhidrosis may contribute to discomfort or self-consciousness in adolescents, it is not a strong independent predictor of anxiety. These results highlight the importance of considering broader psychological and social factors when examining adolescent mental health.

Keywords: hyperhidrosis, adolescent anxiety, sweating disorders, psychological impact, GAD-7

INTRODUCTION

Adolescence is a stage of development where an individual becomes highly responsive to social evaluation, acceptance, and physical appearance. At this stage, physical conditions that affect bodily control or appearance have a psychological or social impact (Schaffer, 2025). One of the physical conditions that affect an individual during adolescence is hyperhidrosis, which is a disorder of excessive sweating.

Hyperhidrosis is a disorder that occurs in approximately 2 to 3% of the world's population, often during adolescence (Monga et al., 2024). The disorder occurs in the palm of the hand, feet, underarms, and face (Pariser et al., 2000). Although hyperhidrosis is not a serious medical disorder, it has a negative impact on daily activities, which include shaking hands, writing, participating in sports, or socializing.

Previous research has indicated that patients with hyperhidrosis tend to experience a poor quality of life and emotional stress. In their systematic review, Sharifi and Jafferany (2025) indicated that children and adolescents with hyperhidrosis tend to experience psychosocial challenges, such as feelings of embarrassment and discomfort.

In their research, Kouris et al. (2015) found that adolescents with hyperhidrosis experienced a poor quality of life and increased social isolation before the intervention.

However, there has been limited research on the relationship between the severity of the symptoms of hyperhidrosis and the levels of anxiety experienced by adolescents. Adolescence is a critical period when peer relationships and perceptions are significant. Therefore, this study sought to investigate the relationship between the severity of the symptoms of hyperhidrosis and the levels of anxiety experienced by adolescents between the ages of 13 and 18 years. The study utilized the Hyperhidrosis Disease Severity Scale and the Generalized Anxiety Disorder-7 scale. Hyperhidrosis can be a disturbing experience for adolescents. Thus, understanding the relationship between the severity of the symptoms and the levels of anxiety experienced by adolescents can increase awareness of the effects of this disease and can inform interventions aimed at helping adolescents with this condition.

Research Question

How does the level of hyperhidrosis severity affect anxiety levels among adolescents between the ages of 13 and 18?

Hypothesis

It is hypothesized that the level of hyperhidrosis severity among adolescents between the ages of 13 and 18 will be positively related to anxiety levels.

Null Hypothesis (H_0)
There is no significant relationship between hyperhidrosis severity and anxiety levels among adolescents.

Alternative Hypothesis (H_a)
There is a significant positive relationship between hyperhidrosis severity and anxiety levels among adolescents.

METHODOLOGY

Study Design

This study adopted a cross-sectional survey design to investigate the association between hyperhidrosis severity and anxiety level among adolescents.

Participants / Sample

This study involved 16 adolescents (n=16), whose ages ranged from 13 years to 18 years. Participants were recruited through convenience sampling by sharing a digital link among the researcher's peers.

Materials / Instruments

Two measurement instruments were adopted in this study.

Hyperhidrosis Disease Severity Scale (HDSS)

This is a measurement instrument designed to measure the perceived severity of excessive sweating and its effect on daily activities. This scale has four severity levels of hyperhidrosis, ranging from minimal effect on daily activities (score=1) to severe effect on daily activities (score=4) (Solish et al., 2007).

Generalized Anxiety Disorder- 7 (GAD- 7)

GAD-7 is a commonly applied measurement instrument for evaluating anxiety level among patients. This instrument has seven questions designed to measure frequency experiences of patients during the last two weeks. Each question is scored on a scale from 0 to 3, resulting in a total score ranging from 0 to 21. Scores are categorized as minimal (0–4), mild (5–9), moderate (10–14), and severe (15–21) anxiety levels (Spitzer et al., 2006).

Other questions were also asked on areas of excessive sweating, climate, and demographic information.

Variables

Independent Variable (IV):
Hyperhidrosis severity measured using the HDSS scale.

Dependent Variable (DV):
Anxiety level measured using the GAD-7 total score.

Controlled Variables:
Age range (13–18), survey format, and measurement instruments remained consistent for all participants.

Confounding Variables:
Climate, gender, and baseline stress levels were recorded but not statistically controlled in the primary analysis

Procedure

Participants accessed the survey through a digital questionnaire link. After confirming eligibility within the age range of 13–18 years, participants completed the HDSS question, the GAD-7 anxiety assessment, and additional demographic questions. All responses were recorded anonymously.

Ethics

Participation was voluntary and anonymous. No identifying information was collected. Data was stored privately and used solely for educational research purposes. Participants provided active consent by selecting "I agree to participate" before accessing the survey questions.

Statistical Analysis Plan

Descriptive statistical analysis was used to summarize the collected data. Frequency distributions were calculated for anxiety categories and hyperhidrosis severity levels. Mean scores and standard deviations were calculated for both the GAD-7 and HDSS scales. These statistics were used to evaluate patterns between hyperhidrosis severity and reported anxiety symptoms. A Pearson correlation coefficient was calculated to assess the relationship between hyperhidrosis and anxiety. A significance threshold of alpha = 0.05 was used to evaluate the hypothesis.

RESULTS (GAD-7 ASSESSMENT)

A total of 16 participants (N = 16) responded to the survey assessing the anxiety levels of the participants using the Generalized Anxiety Disorder–7 (GAD-7) scale.

Anxiety Level Distribution

The anxiety levels of the participants were categorized based on the normal ranges of the GAD-7 scale. The anxiety level distribution is shown in Table 1.

Anxiety Level	Count	Percent
Minimal	4	25%
Mild	8	50%
Moderate	2	12.5%
Severe	2	12.5%

Table 1: *Distribution of Anxiety Levels (GAD- 7)*

Most of the participants (50%) reported mild anxiety levels. In addition, 25% of the participants reported minimum anxiety levels. Few participants reported moderate (12.5%) and severe (12.5%) anxiety levels.

Descriptive Statistics

Individual GAD-7 scores ranged from **0 to 20**. The list of participant scores was:

6, 0, 1, 17, 5, 11, 6, 20, 2, 6, 13, 5, 7, 5, 3, 8.

The mean anxiety score was calculated using the formula:

$$\text{Mean} = \frac{\sum Scores}{n}$$

$$\text{Mean} = \frac{115}{16} = 7.19$$

The mean GAD-7 score was 7.19, which falls within the mild anxiety range according to GAD-7 interpretation guidelines.

The standard deviation was 5.55, indicating a relatively wide spread of anxiety scores among participants.

Summary of Findings

Overall, the results indicate that the majority of participants experienced some level of anxiety, with 75% reporting mild to severe anxiety levels and 25% reporting minimal anxiety. The mean GAD-7 score of 7.19 falls within the mild anxiety range. However, the relatively large standard deviation of 5.55 suggests substantial variability in anxiety levels among participants, indicating that individual experiences differed considerably within the sample.

RESULTS

A total of 16 participants (N = 16) completed the Hyperhidrosis Disease Severity Scale (HDSS) to assess the severity of excessive sweating and its impact on daily activities.

HDSS Severity Distribution

Participants' responses were categorized based on the four HDSS severity levels. The distribution of hyperhidrosis severity is presented in Table 2.

HDSS Level	Description	Count	Percentage
1	Never noticeable, no interference	3	18.75%
2	Tolerable, sometimes interferes	8	50%
3	Barely tolerable, frequently interferes	4	25%
4	Intolerable, always interferes	1	6.25%

Table 2: *Distribution of Hyperhidrosis Severity (HDSS)*

Most of the participants (50%) reported having an HDSS level 2. This shows that the participants experienced the symptom of sweating, although it was tolerable. However, the symptom of sweating sometimes interfered with the participants' daily activities. A quarter of the participants reported having moderate hyperhidrosis (HDSS level 3), while 6.25% reported having severe hyperhidrosis. A few participants (18.75%) reported not experiencing the symptom of sweating.

Descriptive Statistics

Scores for the participants on the HDSS scale ranged from 1 to 4. The list of the scores is as follows:

2, 1, 4, 2, 3, 3, 1, 2, 2, 1, 2, 2, 2, 3, 3, 2.

To calculate the mean of the scores of the participants on the HDSS scale, the following formula is used:

Mean = Sum of the values of the participants / Number of participants

The mean of the participants' scores on the HDSS scale was 2.19. Therefore, the participants experienced mild hyperhidrosis symptoms that sometimes interfered with daily activities.

The standard deviation of the participants' scores on the HDSS scale was 0.75. Therefore, the participants experienced moderate variability in the severity of the sweating.

Summary of Findings

Overall, 81.25% of participants reported experiencing symptoms of hyperhidrosis, indicating that excessive sweating was present in the majority of the sample. Most participants reported mild severity (HDSS level 2), suggesting that symptoms were generally tolerable but occasionally interfered with daily activities. However, a smaller proportion of participants reported moderate to severe symptoms, indicating variability in the impact of hyperhidrosis across individuals.

Sweating Locations

Participants were asked to identify the areas where they experienced the most excessive sweating. Because participants could select multiple options, each location was analyzed by counting the number of responses.

Body Area	Count	Percentage
Underarms	10	62.5%
Face/Head	9	56.25%
Back/Chest	7	43.75%
Palms	6	37.5%
Feet	3	18.75%
No excessive sweating	1	6.25%
Other body areas	1	6.25%

Table 3: *Reported Areas of Excessive Sweating. The area where excessive sweating was most frequently reported was in the underarms, followed by the face/head. Excessive sweating in the palms of the hands and back/chest areas were also frequently reported. However, excessive sweating in the foot area was not as common.*

Climate Distribution

Participants were asked whether they currently live in a tropical or humid climate.

Climate Type	Count	Percentage
Tropical/Humid	7	43.75%
Non-tropical	9	56.25%

Table 4: *Climate Environment of Participants*

The participants of the sample came from tropical and non-tropical climates. More than half of the participants (56.25%) reported living in non-tropical climates, indicating the presence of excessive sweating symptoms regardless of climate conditions.

Gender Distribution

Participants also reported their gender.

Gender	Count	Percentage
Female	7	43.75%
Male	7	43.75%
Non-binary	2	12.5%

Table 5: *Gender Distribution of Participants*

The sample included an equal number of male and female participants, as well as a smaller number of non-binary participants. This represents a wider range of experiences in adolescence.

Correlation Analysis

To assess the association between hyperhidrosis severity and anxiety levels in adolescents, a Pearson correlation analysis was carried out. The analysis was done by considering the HDSS scores and anxiety levels measured by the GAD-7 anxiety scale. The analysis was done to assess whether higher levels of hyperhidrosis severity are associated with higher anxiety levels.

The results obtained from the Pearson correlation analysis revealed a very weak positive association between hyperhidrosis severity and anxiety levels in adolescents (r~ 0.11, R-squared ~0.012, p = 0.69). This indicates that higher levels of hyperhidrosis severity are only minimally associated with higher levels of anxiety and the result is not statistically significant.

The scatter plot and regression line indicate that anxiety levels are distributed across all levels of hyperhidrosis severity. Even though higher levels of HDSS scores correspond to higher levels of anxiety in some individuals, it is evident that the association between these two variables is weak. This indicates that hyperhidrosis severity is not a significant predictor of anxiety levels in adolescents.

It is also worth noting that such an analysis was conducted based on a small sample size, which may limit the strength of such a finding. Further research with a larger sample may yield a better understanding of the correlation between hyperhidrosis and psychological outcomes in teenagers.

Pearson Correlational Analysis:

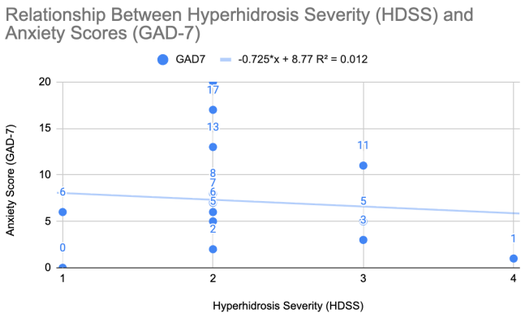

Figure 1: *Scatter plot showing the relationship between hyperhidrosis severity (HDSS) and anxiety scores (GAD- 7). The regression line indicates a negligible correlation (R-squared = 0.012).*

DATA ANALYSIS / DISCUSSION

According to the results of this research, the severity of hyperhidrosis was not an independent predictor of anxiety in adolescents. Although the two places for hyperhidrosis were the armpits (62.5%) and face (56.25%), which are very visible sites in social gatherings, the condition did not significantly correlate with the scores obtained for GAD-7. The results of the present study contradict existing literature on the same topic. According to the literature review by Sharifi and Jafferany (2025), adolescents with hyperhidrosis face many psychosocial problems, and the findings of Kouris et al. (2015) indicate that adolescents with hyperhidrosis tend to be more socially isolated. The difference in results observed in the current research compared to those studies may have been because of the smaller sample size (n=16) or personal factors of the survey respondents.

CONCLUSION

The objective of this study was to investigate the connection between the degree of hyperhidrosis and the level of anxiety among adolescents aged from 13 to 18 years old. It was found that, despite many of the subjects experiencing both excessive sweating and anxiety, there was only a slight positive correlation between the variables.

The low correlation coefficient implies that the severity of hyperhidrosis cannot be considered a sufficient cause for the variability of anxiety among adolescents. It can be concluded that this psychological state may have various sources aside from physiological manifestations, which may include the social environment, personal characteristics, and other factors.

Nevertheless, due to the limited sample size and subjective assessment, the conclusions drawn in this research should be treated cautiously. It does not mean that a different correlation would not be observed in another study with a larger number of respondents.

EVALUATION/LIMITATIONS

Strengths:

A major strength of this study was the use of two established, validated instruments, the HDSS and GAD-7, rather than unvalidated, student-made scales. This ensures that the measurement of both sweating severity and anxiety levels is grounded in recognized clinical standards.

Limitations:

There are limitations to the research since there were very few participants in the sample size at (n=16), making it impossible to conduct any proper statistics. Second, the data collected is subjective because all the data was obtained from the self-reporting of the subjects. Thirdly, the method used in collecting the data was based on convenience sampling.

Improvements / Future Research:

The future studies should increase the sample size by recruiting more individuals to 50 or more students from different schools. In addition, researchers should apply objective methods of measuring sweat rates like gravimetric sweat test method instead of subjective measures like HDSS.

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To what extent do various compositions of macronutrients affect high school students' overall interpretation of their athletic performance during various intensities of sporting activities or exercise?

ABSTRACT

This study investigated the impact of various macronutrient compositions on high school students' perceived athletic performance during high-intensity exercise. The use of a survey (n = 30) on high school students aged 15-18 was analyzed in relation to an experimental design (n = 10) which participants were randomly assigned to specific dietary conditions (high carbohydrate, high lipid, high protein, and a balanced control group). Using a self-report questionnaire, participants then completed the form once every week to rate their perceived performance based on certain categories, including energy level, fatigue, focus, etc. The results from both the survey and experimental design were analyzed using statistical analysis and tools, including a Pearson correlation, an independent t-test, and a one-way ANOVA. The results showed that there was a positive correlation between carbohydrate intake and perceived performance ($r = 0.42$, $p = 0.021$), a nonsignificant difference in protein ($r = 0.21$, $p = 0.264$), and a negative correlation for lipid intake ($r = -0.36$, $p = 0.048$). A one-way ANOVA determined a statistically significant difference between the different dietary conditions ($F = 4.12$, $p<0.05$), with a large difference between high-carbohydrate and high-lipid. These findings show that macronutrient compositions, specifically carbohydrate intake, play a role in shaping high school students' perception of their athletic performance during high-intensity exercise.

INTRODUCTION

Nutritional balance plays a critical role in shaping both the physiological and psychological experiences of adolescent athletes. However, the extent to which specific macronutrient compositions, particularly the ratio of carbohydrates, proteins, and fats, influence high school students' perceptions of their own athletic performance remains underexplored. Adolescence is characterized by rapid growth and increased metabolic demands, requiring higher energy intake to support both development and physical activity (Desbrow et al., 2014). When these energy needs are not met, athletes may experience fatigue, reduced concentration, and decreased endurance, all of which can negatively influence both academic engagement and athletic performance.

Macronutrient composition is especially important in regulating how athletes perceive their level of exertion during exercise. Carbohydrates serve as the primary fuel source for moderate to high-intensity activity, as they are rapidly converted into glucose and stored as glycogen for immediate energy use (Baker et al., 2015; Thomas et al., 2016). Research shows that depletion of glycogen stores is strongly associated with increased fatigue and reduced power output, which can directly elevate an athlete's Rating of Perceived Exertion (RPE) (Williams & Rollo, 2015). As a result, insufficient carbohydrate intake may cause athletes to interpret their performance as more physically demanding, even if objective performance remains unchanged.

In contrast, diets that restrict carbohydrates, such as low-carbohydrate, high-fat (LCHF) or ketogenic diets, have been shown to negatively affect high-intensity performance. Studies indicate that athletes who followed these diets experienced earlier fatigue and higher perceived exertion compared to those consuming adequate carbohydrate levels (Henselmans et al., 2022; Burke et al., 2017). While lipids provide a valuable long-term energy source, their

slower metabolic rate makes them less effective in supporting short-duration, high-intensity exercise (Emine Elibol, Burcu Nur Çaylak, & Sema Gol, 2025). Similarly, although protein is essential for muscle repair and recovery, excessive protein consumption at the expense of carbohydrates may reduce available energy for immediate performance (Phillips & Van Loon, 2011).

Beyond physiological factors, environmental and social influences further shape dietary habits and performance perceptions among high school athletes. Limited access to nutritious food, financial constraints, and dependence on family-provided meals can restrict students' ability to maintain an optimal diet. These barriers may create a disconnect between nutritional knowledge and actual intake, contributing to increased fatigue and lower confidence in physical preparedness (Desbrow et al., 2014).

Overall, existing research suggests that carbohydrate availability plays a central role in both physical performance and perceived exertion during high-intensity exercise. However, most studies focus on objective performance outcomes rather than subjective interpretations of performance, particularly among adolescent populations. Therefore, this study aims to investigate how varying macronutrient compositions influence high school students' perceived athletic performance across different exercise intensities. Understanding these relationships is essential, as athletes' perceptions of their physical capabilities can significantly influence motivation, confidence, and long-term participation in sports.

Hypothesis

H_0 (Null Hypothesis): There is no significant relationship between varying macronutrient ratios and high school students' perception of their athletic performance during high-intensity exercise.

H_a (Alternative Hypothesis): There is a significant relationship between varying macronutrient ratios and high school students' perception of their athletic performance during high-intensity exercise.

Key Definitions

High Intensity Exercise - Forms of exercise that are characterized by repeated bursts of intense energy consumption, often exceeding 80% of heart rate, followed by periods of brief recovery.

Adolescent - A young person who is developing into an adult.

Perceived Performance - How one feels before, during, and after a period of intensive exercise/sporting activity, not only physical, but mentally.

MATERIALS AND METHODS

Study Design

This study employs two distinct study designs. An experimental design and a survey. They are used and analyzed together to identify a correlation or trend between varying macronutrient ratios and the impact on perceived performance among high school students participating in high-intensity exercise or sporting activities.

Part A: Survey

Participants/Sample

The researcher studied and sampled only High School students (male and female) whose ages range from 15 to 18 years old. The researcher's participants were recruited through convenience sampling. The survey was distributed to the researcher's personal contacts and posted on a Reddit community dedicated to survey exchanges and communication.

The final sample size of the survey was n=30 (30 participants), which ensured that the central limit theorem was met. Exclusions from the sampling group are anyone who isn't a high school student, as this research question doesn't apply to them.

Demographic Distribution of Participants by Age and Gender

Age Group	Participants (n)	Male Participants	Female Participants
18-year-olds	17	10	7
17-year-olds	5	5	0
16-year-olds	5	4	1
15-Year-Olds	3	1	2

Table 1: *Demographic Distribution of Participants by Age and Gender*

Ethics

All participants consented to answer the survey; additionally, all participants are anonymous, such that no names are publicly released. The only person who can access the raw data is the researcher himself and his supervisor.

Part B: Experimental Design

Participants/Sample

The researcher studied and sampled only High School students who are actively participating in a seasonal sport at school. Intensity of training varied from person to person, but a consistent trend of at least three trainings per week. Participants were selected using convenience sampling, as participants were recruited through personal networks and connections (friends, classmates, teachers' recommendations, etc).

The final sample size is n=10, meaning that 10 participants were actively contributing to the results of this experimental design. Participants were excluded if they did not participate in seasonal sports, were not capable of following the assigned macronutrient diet, or failed to complete check-in forms to create experimental results.

Materials/Instruments

This experimental design uses pre-planned diets with varying macronutrient ratios, tracked through a mobile dietary tracking app, MyFitnessPal, to ensure participants stick to their assigned diets. Perceived athletic performance was measured through check-in forms using a self-report scale, such as a Likert scale, with 1 representing not helpful in perceived performance and 5 being very helpful in perceived performance, in which participants would rank their physical/mental well-being after each week of their training based on various factors, including energy level, fatigue, motivation, and more.

Variables

Independent Variable (IV)

- The macronutrient composition of the participants' diets
  - High Carbohydrates
  - High Protein
  - High Lipids
  - Control

Dependent Variable (DV)

- Participants' perceived athletic performance is tracked using weekly check-in forms that include numerical scales determining how they feel about their performance physically and mentally.

Control Variable (CV)

- Time of Check Ins
- Training Frequencies
- Same Diet-tracking method

Confounding Variables

- Overall Fitness Level
- Type of Sport
- Sleep
- External Stress Factors

These confounding variables were controlled as best as possible throughout the study, but not all of them could be fully accounted for. Participants were selected based on their regular involvement in school sporting activities, but variation in intensity and fitness level could not be controlled. Additionally, the amount of sleep and external factors are tracked through self-reports, making it extremely difficult to be reliably monitored.

Macronutrient Composition of Each Dietary Condition

Diet Type	Protein (%)	Carbohydrates (%)	Lipids (%)	Total %
High Carbohydrate	18	51	31	100
High Protein	35	40	25	100
High Lipids	20	25	55	100
Control	33	33	33	100

Table 2: *Macronutrient Composition of Each Dietary Condition*

Procedure

This experimental design was carried out over the span of four weeks. Participants were first assigned to one of four dietary groups: high carbohydrate, high protein, high lipid, or a control group with no specific macronutrient intake. Random assignment was also conducted to ensure that the researcher could infer causation based on the results. Before the experiment, the researcher gathered informed consent and debriefed each participant on the basis of the experiment.

Throughout the four weeks, participants followed their assigned diet while continuing their seasonal sport training. The required amount of training per participant was three times a week in order to see consistent data and results. Through the use of a mobile dietary tracking app, each participant was able to log and track their assigned diets.

At the end of each week, participants were asked to complete a check-in form to assess how they perceived their athletic performance throughout the week. This form utilizes a Likert scale and short answer questions, assessing crucial factors such as energy levels, fatigue levels, and overall physical and mental fitness. All participants were told to complete the check-in form at the same time to reduce variability in the time of responses, which could have an impact on the final results.

All collected data from each participant was kept anonymous and organized, which will be used to statistically analyze certain trends or patterns that appear.

Ethics

All participants provided informed consent before the start of the experimental design. The purpose of the study was clear, and no deception was present. Participants could withdraw from the study at any time if they felt that they couldn't stick to the planned diet or couldn't provide the necessary information. Names were kept anonymous, and only the researcher and his supervisor can access the raw data.

It is also crucial to protect the well-being of the participants and ensure that no participant's physical or mental well-being is hurt throughout the process of this experimental design. Each diet was verified to be safe and reasonable, and follows the nutritional guidelines.

Statistical / Analysis Plan

Results and data from the experimental design were analyzed using descriptive and analytical inferential statistics. The researcher applied an ANOVA (Analysis of Variance) test to compare mean perceived performance scores from the check-in forms across the four dietary groups. Before conducting the ANOVA test, the researcher checked for normality and homogeneity of variance by observing the data distribution and comparison of standard deviations between the dietary conditions, and no major differences were found. This allowed the researcher to determine whether there was a statistically significant difference between the different treatment groups. A significance level of $\alpha = 0.05$ for all of the statistical tests. If the p-value is less than the significance level, it indicates that there is a significant difference in the macronutrient ratio diets and high school students' perceived performance during high-intensity exercise. Independence was checked to ensure that there was limited bias in the gathering of data.

RESULTS

Part A: Survey

Distribution of Macronutrients on Perceived Athletic Performance (n = 30)

Macronutrient	Frequency (n)	Percentage (%)
Carbohydrates	19	63
Protein	8	27
Lipids	3	10

Table 3: *Distribution of Macronutrients on Perceived Athletic Performance*

Macronutrient Preference Influencing Athletic Performance by Gender

Macronutrient	Male (n = 20)	Female (n = 10)
Carbohydrates	14 (70%)	5 (50%)
Protein	5 (25%)	3 (30%)
Lipids	1 (5%)	2 (20%)

Table 4: *Macronutrient Preference Influencing Athletic Performance by Gender*

Descriptive Statistics for Perceived Impact of Macronutrients on Athletic Performance (Likert Scale 1-5)

Macronutrient	Mean (M)	Standard Deviation (SD)
Carbohydrates	4.2	0.5
Protein	3.7	0.5
Lipids	3.4	0.6

Table 5: *Descriptive Statistics for Perceived Impact of Macronutrients on Athletic Performance*

Summary of Inferential Statistics for Survey Data

Statistical Test	Variables Compared	Test Statistic	P-Value	Decision
Pearson Correlation	Carbohydrates + Perceived Performance	$r \cong 0.42$	$0.021 < 0.05$	Reject H_0
Pearson Correlation	Protein + Perceived Performance	$r \cong 0.21$	$0.264 > 0.05$	Fail to Reject H_0
Pearson Correlation	Lipids + Perceived Performance	$r \cong -0.36$	$0.048 < 0.05$	Reject H_0
Independent t-test	Male + Female	$t \cong 1.32$	$0.197 > 0.05$	Fail to Reject H_0

Table 6: *Summary of Inferential Statistics for Survey Data*

The distribution of responses for the perceived macronutrient influence on one's athletic performance is shown in Table 3. Out of 30 responses, 19 participants identified carbohydrates as the primary macronutrient that most influences their perception of athletic performance, while 8 participants selected protein and 3 selected lipids.

Macronutrient preferences for influencing athletic performance by gender are highlighted in Table 4. Among the male responses, 14 selected carbohydrates, 5 selected proteins, and 1 selected lipid. Among the female participants, 5 selected carbohydrates, 3 selected proteins, and 2 selected lipids.

Descriptive statistics for perceived impact ratings of macronutrients on athletic performance are presented in Table 5. Carbohydrates had the highest mean perceived score with a mean of 4.2 and standard deviation of 0.5, followed by protein with a mean of 3.7 and standard deviation of 0.5, and lipids with the least, with a mean of 3.4 and standard deviation of 0.6.

Various Inferential statistical tests were used to produce the results in Table 6. A Pearson correlation test was used to determine the relationship between macronutrient intake levels and perceived impact on athletic performance. For carbohydrates, there was a moderate positive correlation with an r value of approximately 0.42, with the p-value being less than the significance level of 0.05. Additionally, for lipids, there was a moderate negative correlation with an r value of approximately -0.36 and a p value less than 0.05. For both relationships, the null hypothesis was rejected. However, the relationship between protein intake and perceived athletic performance showed a weak positive correlation with an r value of approximately 0.21 and a p-value greater than the significance level of 0.05, indicating that there isn't a significant relationship between the two, therefore failing to reject the null hypothesis.

Lastly, an independent t-test was conducted to determine the difference in perceived athletic performance between male and female participants. Male participants reported a mean score of 3.9 and a standard deviation of 0.5 on a 5-point Likert scale. On the other hand, female participants reported a mean of 3.6 and a standard deviation of 0.6. The results are not statistically significant, and the null hypothesis cannot be rejected.

Part B: Experimental Design

Mean Perceived Performance Scores by Dietary Group (n = 10)

Dietary Group	Mean (M)	Standard Deviation (SD)	Range
High Carbohydrate	4.3	0.5	4-5
High Protein	3.7	0.5	3-4
High Lipid	3.2	0.6	2-4
Control	3.9	0.4	3-4

Table 7: *Mean Perceived Performance Scores Based on Dietary Conditions*

One-Way ANOVA Results Comparing Perceived Performance Across Dietary Groups

Source of Variation	Degrees of Freedom (df)	Sum of Squares	Mean Squares	F-value	P-value	Decision
Between Groups	3	2.47	0.82	4.12	0.048 < 0.05	Reject Ho
Within Groups	6	1.20	0.20	N/A	N/A	N/A
Total	9	3.67	N/A	N/A	N/A	N/A

Table 8: *One-Way ANOVA Results Comparing Perceived Performance Across Dietary Groups*

Post-Hoc Tukey HSD Test Results For Comparison Between Dietary Groups

Comparisons	Mean Difference	P-Value	Significance
High Carbohydrate vs High Lipid	1.1	0.032<0.05	Significant
High Carbohydrate vs Control Group	0.4	0.412>0.05	Non Significant
High Carbohydrate vs High Protein	0.6	0.238>0.05	Non Significant
Control vs High Protein	0.2	0.671>0.05	Non Significant
Control vs High Lipid	0.7	0.118>0.05	Non Significant
High Protein vs High Lipid	0.5	0.295>0.05	Non Significant

Table 9: *Post-Hoc Tukey HSD Test Results for Comparison Between Dietary Groups*

Descriptive Summary of Weekly Perceived Performance Scores by Dietary Groups

Dietary Group	Median	Minimum	Maximum
High Carbohydrate	4.5	4	5
High Protein	4.0	3	4
High Lipid	3.5	3	4
Control	3.0	2	4

Table 10: *Descriptive Summary of Weekly Perceived Performance Scores by Dietary Groups*

The mean perceived performance scores for each dietary group are shown in Table 7. The high carbohydrate group had the highest mean score of 4.3 and a standard deviation of 0.5, followed by the control group with a mean of 3.9 and a standard deviation of 0.4. The high protein group had a mean of 3.7 and a standard deviation of 0.5, and finally, the lipid group had a mean of 3.2 and a standard deviation of 0.6.

A one-way ANOVA test was used to compare the mean perceived athletic performance across the four treatment groups. The variation between groups, specifically a F-value of 4.12 and a p-value less than 0.05, indicates that the data is statistically significant and the null hypothesis was rejected.

To determine which specific dietary groups differed from each other, the researcher conducted a post-hoc Tukey HSD test. The results from the test indicated that the high carbohydrate group and the high lipid group showed a significant difference (mean difference 1.1, p=0.032 < 0.05). All other comparisons were not statistically significant, suggesting that overall these groups did not differ meaningfully in perceived performance.

The descriptive statistics summary presented in Table 10 shows that the median response for the high carbohydrate group was highest, with a median of 4.5, and lowest for the high lipid group, with a median of 3.0. The difference between minimums and maximums indicates that there was variability within the responses from the weekly check-in forms.

DATA ANALYSIS

The results from the survey and experimental design both show the same correlations between varying macronutrient ratios and their impact on high school students' interpretation of their athletic performance during high-intensity exercise. In the survey, carbohydrates were rated the highest when it came to their impact on the interpretation of athletic performance. On the other hand, lipid was the most negatively rated when it came to impacting their interpretation of their athletic performance, with protein falling in between the two.

In the experimental design, the high-carbohydrate dietary group also showed similar results, with the group having the highest mean score of perceived athletic performance at 4.3. In contrast, the high lipid dietary group recorded the lowest with 3.2. The protein was again in between the two macronutrients, indicating that protein plays a more long-term role in impacting athletic performance rather than a short-term one.

The one-way ANOVA indicated a statistically significant difference between the dietary groups, indicating that macronutrient ratio compositions do influence perceived performance in high school athletes.

The variability between dietary compositions suggests that each individual responds to the intake of macronutrients differently. Other factors, including metabolism, fitness level, type of sports they participate in, or prior diets that may have influenced perceived performance, all played a significant role in the outcomes. However, no extreme outliers or deviations from the trend were observed.

These findings align with previous research, alluding to the pattern that can be explained by the different physiological functions of each macronutrient. Carbohydrates are used as the primary source of energy during exercise, as they are constantly being used to produce glucose for quick release of energy. This is what makes athletes perceive their performance more positively due to being able to see a fast change in their performance. On the other hand, lipids are just as important but are used differently. They are consumed and processed more slowly as they aren't used for quick energy but for long-term energy; therefore, they might contribute to lower perceived performance scores. Now, for protein, protein is known for its correlation with muscle and muscle repair. Rather than energy like lipids and carbohydrates, protein is used for recovery of muscle fibers and strengthening of the muscles, which aren't as quickly noticeable as carbohydrates or lipids, hence its intermediate responses.

In a practical sense, these findings from the survey and experimental design indicate that high school athletes would benefit most from carbohydrate intake to support their high-intensity training, while protein is used for long-term repair and maintenance, and lipids for overall health and longevity. When using the results from both the survey and the experimental design, a clear pattern arises. Carbohydrates have a heavy association with higher perceived athletic performance than the other two macronutrients. However, lipid is associated with lowered perceived performance.

CONCLUSION

The overall study aimed to determine the extent to which various macronutrient ratios impact high school athletes' interpretation of their athletic performance during high-intensity exercise. The results showed that certain macronutrient compositions do have an impact on athletic performance. More specifically, carbohydrate-rich diets were linked with improved performance, while lipid-rich diets were associated with negative performance. Overall, the findings provide evidence that the impact of macronutrients is present. The alternative hypothesis was supported, which stated that there is a significant difference between macronutrient composition and perceived performance. These findings are crucial because improved perceived performance not only benefits athletes physically but also mentally as well. It can improve motivation, confidence, and overall well-being. In the future, these findings can be used as a stepping stone to prioritize the balance of nutritional diets to improve academic and athletic performance.

EVALUATION/LIMITATIONS

This study utilized several methodological strategies to contribute to the reliability and validity of the results. A combination of a survey (n = 30) and an experimental design (n = 10) allowed for both results to be cross-analyzed to find correlations between the two forms of data collection. Additionally, the inclusion of multiple treatment categories of nutritional diets strengthened the validity of the results by allowing the researcher to conduct specific inferential analyses.

Despite these strengths, several limitations may have an impact on the generalizability and accuracy of the findings. Such limitations include a small sample size in the experimental design, which can reduce the generalizability and statistical significance of the results, and a biased convenience sample, causing limited representation of the sample, as participants were recruited from personal connections and online platforms. The measurement of the experimental design could also introduce self-response bias. Although confounding variables such as overall fitness level, the type of sport, the amount of quality sleep, and external stress were attempted to be considered, they could not be fully controlled and accounted for. This introduces the potential for there to be additional variability within the results.

To improve the overall study, the researcher could expand the sample size to about 60 students and make a stratified sample through the type of sports, fitness level, etc, to account for the confounding variables present. Additionally, the researcher could provide standardized meals for each of the dietary conditions instead of solely relying on self-tracking, which could overall reduce self-response bias. Lastly, the researcher could add an objective performance metric to determine whether or not there is actual statistical improvement in one's timed endurance test, heart rate, and more. If these improvements were implemented, they would overall improve the statistical significance, reliability, reduce variability, and applicability to future research.

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To what extent does injury duration influence the levels of sport-related anxiety experienced by high school athletes during their return to sport?

ABSTRACT

This study investigates the extent to which injury duration influences sport-related anxiety levels experienced by high school athletes during their return to sport (RTS). Employing a cross-sectional mixed-methods design, the study assessed 34 high school athletes in Vietnam—divided evenly into short-term (< 3 weeks) and long-term (≥ 3 weeks) injury cohorts—using the Sport-Anxiety Scale-2 (SAS-2) alongside open-ended qualitative questionnaires. Quantitative data were analyzed using independent-samples t-tests to evaluate differences in cognitive worry, somatic trait anxiety, and concentration disruption, while qualitative responses were analyzed to explore themes of fear, confidence, and coping mechanisms. Results indicated that long-term injured athletes experienced practically meaningful increases in cognitive worry (Cohen's d = 0.53) and slightly elevated somatic anxiety compared to their short-term counterparts, though concentration disruption remained unaffected. Qualitatively, long-term athletes reported persistent re-injury fears, severe athletic identity disruption, and a reliance on structured coping strategies, contrasting sharply with the fleeting, self-resolving doubts of short-term athletes.

INTRODUCTION

Sports injuries impose significant psychological barriers on athletes that frequently persist beyond physical recovery, yet the role of injury duration as a distinct psychological factor remains unknown. While prior research on sports injuries has established that fear of re-injury, reduced self-efficacy, and heightened sports anxiety are common during return to sport (RTS) (Podlog & Eklund, 2006; Shuer & Dietrich, 1997), much of this research has focused on elite and professional athletes, where detailed sports psychology is rooted as part of their athletic programs. Shuer and Dietrich (1997) found that chronically injured collegiate athletes experience intrusive thoughts about their injuries at similar levels to victims of natural disasters, with psychological distress remaining elevated regardless of injury duration–even past the first year benchmark. On the other hand, high school athletes navigate psychological worries of injury and recovery largely without access to such structured support, while simultaneously experiencing pressures between academic work, coaches, parents, and teammates.

This ties into many substantial concerns, such as losing one's starting position on a team, the effects on academic performance and social relationships, and the gradual disappearance of the social identity associated with athletic participation. Podlog and Eklund's (2006) longitudinal investigation revealed that preserving athletic identity was a primary motive for return to sport among all athletes–more specifically, competitive athletes–with five participants indicating they felt "worthless" without their athletic role. Furthermore, self-presentational concerns—including fears of not meeting others' expectations, letting down teammates, and upholding one's reputation—were particularly noticeable among athletes with prolonged absences (Podlog & Eklund, 2006). These compounding stressors suggest that understanding how injury duration and severity shape psychological outcomes in this population warrants closer examination. Research has demonstrated that athletes with chronic injuries face sustained re-injury fears, with Podlog and Eklund (2006) reporting that five of six chronically injured athletes experienced heightened concerns, and four continued to experience persistent fears throughout an entire 6-8 month competitive season. In contrast, athletes recovering from acute injuries with no ongoing pain saw their re-injury fears dissipate almost immediately once physical symptoms resolved (Albishi, 2025). Sustained re-injury fears are common among athletes with chronic injuries.

Using the Sport-Anxiety Scale-2 (SAS-2), this study investigates how short-term versus long-term injury duration influences somatic anxiety, cognitive worry, concentration disruption, and psychological readiness among high school athletes returning to sport. It is hypothesized that athletes recovering from long-term injuries will report significantly higher sport anxiety and greater psychological barriers to return compared to those recovering from short-term injuries.

H_0: Injury duration (short-term vs. long-term) does not significantly affect sport anxiety levels in high school athletes returning to competition.

H_1: Long-term injury duration significantly increases sport anxiety levels compared to short-term injury duration in high school athletes returning to competition.

METHODOLOGY

Design & Sample

A cross-sectional study was conducted using both quantitative and qualitative methods to compare two groups of high school athletes categorized by the duration of their injury. Participants were primarily recruited from the high school athletics student body of Saigon South International School (SSIS) and, to a lesser extent, the International School Ho Chi Minh City (ISHCMC), both located in Ho Chi Minh City, Vietnam. The researcher distributed Google Forms via email to all student-athletes currently enrolled in, or who have played in, previous seasons of the high school athletics program. This form was directed to students who have experienced a sports-related injury within the current or previous academic year.

Sample characteristics:

- **Total N** = 34 high school athletes
- **Short-term injury group (n = 17)**: Athletes with injury duration less than 3 weeks
- **Long-term injury group (n = 17)**: Athletes with an injury duration of 3 weeks or more

The definition of injury duration in this study was the total time during which an athlete was unable to fully participate in training and competition. A three-week cutoff was employed to categorize injuries, separating acute injuries with short recovery times from those necessitating longer rehabilitation. This standard aligns with established sports injury literature, which classifies injury severity by time lost (Podlog & Eklund, 2006). Athletes reported the duration of their injuries via self-report on the survey, which subsequently determined their assignment to the respective study groups.

INSTRUMENTS

Sport-Anxiety Scale-2 (SAS-2)

The first section of this study utilizes the Sport-Anxiety Scale-2 (SAS-2; Smith et al., 2006), a validated 21-item psychological questionnaire designed to measure sport anxiety across three sub-scales: cognitive worry (mental concerns about performance failure and negative evaluation), somatic anxiety (physical symptoms of anxiety), and concentration disruption (difficulty focusing and staying mentally present during competition). Participants responded to each item using a four-point Likert scale ranging from 1 (not at all) to 4 (very much so), with higher composite scores indicating greater levels of sport-related anxiety.

The calculation for each sub-scale of the SAS-2 is listed as:

- **Worry Score:** add up questions 3, 5, 9, 10, 13, 16, 18.
- **Concentration Disruption Score**: add up questions 2, 6, 7, 14, 20.
- **Somatic Trait Anxiety Score**: add up questions 1, 4, 8, 11, 12, 15, 17, 19, 21.

Open-Ended Qualitative Questions

The second section of the survey consisted of a series of open-ended questions designed to capture qualitative insights into athletes' psychological experiences during return to sport. These questions assessed three key components:

- **Fear and psychological readiness**: "Do you worry about reinjury? When do these thoughts happen?" and "What makes you feel ready or not ready to return to your sport?"
- **Confidence and anxiety**: "What steps have you taken to rebuild your confidence?" and "How has the injury affected how you see yourself as an athlete?"
- **Coping and mindset progression**: "What helps you manage fear during training or rehab?" and "How has your mindset changed throughout your rehab journey?"

This mixed-methods approach utilized both quantitative and qualitative data: statistical comparisons from the SAS-2 findings and rich, contextualized data from participants' detailed responses. This allowed for a deeper understanding of the lived experiences of high school athletes returning from injury, complementing the inter-group statistical comparison.

Materials

The study collected data using Google Forms, an anonymous online survey platform, to encourage honest responses. The survey included two main parts: the 21-item Likert-scale questionnaire (SAS-2) and open-ended text fields for qualitative data. Participants received access to the survey through a unique email link. Demographic information collected covered age, gender, specific sport, injury type, and injury duration. The survey generally took 10 to 15 minutes to complete.

Procedure

Following approval from the school's athletic department and an independent research class, the researcher sent email invitations to all high school athletes in the SSIS athletics program. Participants from other educational institutions were recruited through the researcher's established professional network with peers at ISHCMC. The email contained a brief description of the study and survey purpose, information about confidentiality and voluntary participation, and a link to the Google Form survey.

Data collection remained open for approximately one month to allow all eligible athletes sufficient time to respond. Reminder emails were sent after the 2-week mark after the initial invitation to maximize participation rates. This recruitment method introduced volunteer bias, as only athletes willing to complete the survey participated. Consequently, findings may not generalize to all high school athletes, particularly those less inclined to engage with self-report psychological measures or those with different injury experiences who chose not to respond.

Ethics

This research was conducted with approval from the researcher's supervising teacher and the SSIS athletic director. Surveys were distributed via email to all high school student-athletes; however, participation could not be verified, meaning it was not possible to confirm whether each respondent was an athlete or a non-athlete.

Participation was voluntary, with students providing implicit consent by completing the survey. Parental consent for participants under 18 was not obtained, which poses certain methodological limitations, though the minimal-risk nature of sport anxiety questions mitigated any potential harm.

Confidentiality was achieved as all identifying information collected by the Google Form was ultimately removed during analysis. Only the aggregated data appeared in the published results. Raw data was accessible solely to the researcher, research supervisor, and statistics teacher.

Analysis Plan

Quantitative Analysis

Descriptive statistics: Means, standard deviations, and ranges were calculated for each SAS-2 subscale (somatic anxiety, worry, concentration disruption) within both the short-term and long-term injury groups.

Inferential statistics: To compare mean subscale scores between the short-term and long-term injury groups, independent-samples t-tests were used. Statistical significance was defined as $p < .05$, and Cohen's d was calculated to quantify the magnitude of differences between groups (effect sizes).

Qualitative Analysis

Responses to open-ended questions were analyzed to compare how athletes with short-term vs. long-term injuries differed in their strategies for overcoming psychological barriers and in shifts in mindset during their return to sport. The researchers grouped responses for recurring themes related to coping strategies (e.g., seeking medical clearance, using social support, mental preparation techniques) and mindset progression (e.g., changes in confidence, fear management, psychological readiness over time). Themes were compared between groups to determine whether injury duration influenced not only anxiety levels (SAS-2 scores) but also the coping mechanisms employed and the trajectory of psychological recovery throughout the return-to-sport process.

RESULTS

Quantitative Analysis

Data Processing Summary

Table 1 presents the comparative mean scores across the three SAS-2 subscales. Long-term injury athletes demonstrated elevated levels of anxiety across two of the three measured scales, with the most substantial difference observed in Cognitive worry.

Subscale	Short-Term Injury Mean (n=17)	Long-Term Injury Mean (n=17)	Difference	Standard Deviation (ST)	Standard Deviation (LT)
Worry (Cognitive)	16.82	19.53	+2.71	5.42	4.8
Somatic Trait Anxiety	18	19.76	+1.76	5.99	6.12
Concentration Disruption	9.47	9.35	-0.12	3.72	3.33

Table 1: *Comparative Mean Scores by Injury Duration*

Visual Presentation

Figure 1 (see below) illustrates the mean scores for short-term and long-term injuries across all three psychological inhibitor subscales. The grouped bar chart allows for immediate visualization of differences between two groups, with blue bars representing short-term and red bars representing long-term injuries. The X-axis clearly outlines the three distinct psychological subscales measured by the SAS-2, while the Y-axis spans from 0 to 30, encompassing the full possible range of subscale scores.

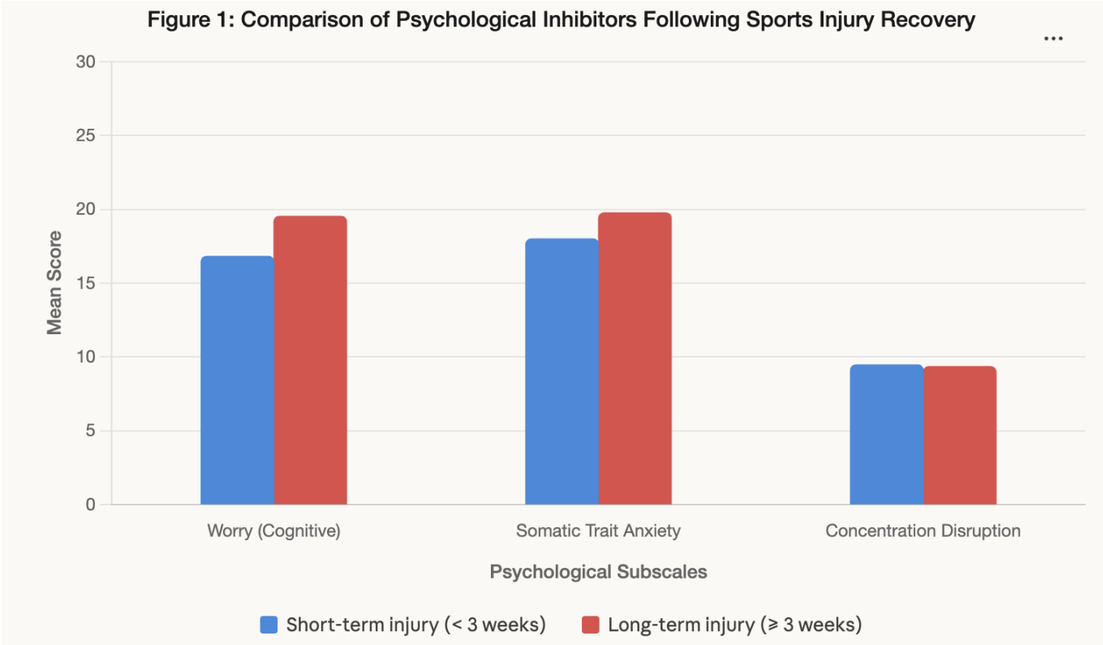

Figure 1: *Comparison of Psychological Inhibitors in Short-term (n = 17) and Long-term (n = 17) Injury Duration*

Inferential Statistics

Independent-samples t-tests were conducted to compare mean SAS-2 subscale scores between short- and long-term injury groups. Table 2 presents the results of the statistical analyses, including t-values, degrees of freedom, p-values, and effect sizes (Cohen's d).

Subscale	t-value	df	p-value	Cohen's d	Statistical Significance
Cognitive Worry	1.54	32	0.133	0.53	Not significant ($p > 0.05$)
Somatic Trait Anxiety	0.85	32	0.403	0.29	Not significant ($p > 0.05$)
Concentration Disruption	-0.1	32	0.921	-0.03	Not significant ($p > 0.05$)

Table 2: *Independent Samples T-Test Results*

**Note: Alpha level set at $p < 0.05$ for determining statistical significance. Effect sizes are interpreted as small (d = 0.2), medium (d = 0.5), or large (d = 0.8).*

None of the observed differences between short-term and long-term injury groups reached statistical significance at the conventional alpha level of $p < 0.05$. Cognitive Worry approached significance ($p = 0.133$), while Somatic Trait Anxiety ($p = 0.403$) and Concentration Disruption ($p = 0.921$) showed no statistically significant differences between groups.

Effect size analysis revealed that Cognitive Worry exhibited a medium effect (Cohen's d = 0.53), Somatic Trait Anxiety showed a small effect (Cohen's d = 0.29), and Concentration Disruption demonstrated a negligible effect (Cohen's d = -0.03). The medium effect size for Cognitive Worry suggests a practically meaningful difference despite the lack of statistical significance.

Qualitative Findings

*Short-term injury participants are referred to as: ST-01, ST-02, ..., ST-17
*Long-term injury participants are referred to as: LT-01, LT-02, ..., LT-17

Fear and Psychological Readiness

Athletes in both groups reported concerns about reinjury, though these differed in intensity and scope. Short-term injury athletes described situational worry tied to specific moments, such as facing aggressive opponents or replicating the movement that caused the original injury. ST-09 noted worry arising "when I know that I will be going into [a] situation similar to the one that caused it." Several short-term athletes reported minimal or no concern, with ST-13 stating, "I don't [worry] because I'm confident I can prevent it from happening again."

Long-term injury athletes described more pervasive and emotionally intense fears. LT-01 reported experiencing "PTSD of getting injured again" every time he stepped on the court. At the same time, LT-16 indicated that fear actively restricted behavior, stating it "stops me from doing things I used to do." LT-09 described hesitation triggered by fast movements, bad landings, or performance pressure, noting, "my mind remembers the past injuries."

Regarding readiness, short-term athletes defined it almost exclusively in physical terms—specifically, the absence of pain. ST-01 felt ready "when I can comfortably play the sport without any stress or pain in the injured area." Long-term athletes incorporated psychological criteria alongside physical recovery. LT-05 described readiness as requiring both physical stability and the absence of hesitation, while LT-16 expressed ongoing uncertainty about whether he could "trust my knee."

Confidence and Anxiety

Short-term injury athletes generally reported minimal disruption to athletic confidence. Several framed injuries are routine, with ST-09 stating, "I don't lose my confidence after an injury, it's part of sports." When confidence was affected, the impact was described as brief and self-resolving.

Long-term injury athletes reported more substantial effects on self-perception, with a recurring theme of newfound vulnerability. LT-07 stated, "I saw myself as not invincible," and LT-09 described becoming "more aware of my body and my limits instead of feeling unstoppable." LT-02 reported the most severe impact, describing "lost all motivation," while LT-16 noted concrete performance declines affecting self-image.

Confidence-rebuilding strategies also differed. Short-term athletes relied on straightforward approaches such as returning to practice and performing strengthening exercises. Long-term athletes were more likely to employ structured, progressive goal-setting. LT-01 described advancing from single-leg balance holds to directional changes, noting that "making small goals to achieve a larger goal has helped me gain confidence in my ankle." Notably, LT-07 admitted, "I haven't ever taken steps to rebuild confidence," suggesting that some long-term athletes lacked the resources to address their loss of confidence.

Coping Strategies and Mindset Progression

Short-term athletes described informal, intuitive coping strategies including distraction (ST-01: "music and people around me"), self-talk (ST-02: "just play, don't worry about it"), and social support from teammates. Long-term athletes described more deliberate approaches, with LT-05 citing "trusting the process" and LT-09 emphasizing structured rehabilitation and controlled movements. However, some long-term athletes indicated that no strategy was effective, with LT-16 stating, "I just gotta feel the anxiety and wait for it to pass."

Mindset progression also differed between groups. Short-term athletes reported modest shifts, such as increased health awareness or empathy for injured peers, with several reporting no change at all. Long-term athletes described more transformative arcs—most commonly a transition from frustration to patience. LT-09 captured this progression: "at the beginning of my rehab, I felt frustrated, scared, and impatient... over time, my mindset changed. I became more patient and focused on small improvements instead of rushing." LT-07 described learning self-compassion, recognizing that "my injury could've happened to any athlete in the team." Not all long-term athletes achieved resolution, however; LT-02 described remaining "always in pain," suggesting incomplete psychological recovery.

DISCUSSION

Quantitative Analysis

Cognitive Worry

The data reveal a notable positive correlation between injury duration and cognitive worry. Athletes in the long- term injury group scored 16.1% higher in Cognitive Worry (19.53) compared to their short-term counterparts (16.82), showcasing a difference of +2.71 points. Although this difference did not reach statistical significance at the conventional alpha level ($p = 0.133$), it exhibited a medium effect size (Cohen's $d = 0.53$). This suggests a practically meaningful difference between the two groups, with the lack of statistical significance likely due to insufficient power given the small sample size ($n = 17$ per group). Ultimately, these findings suggest that extended time away from sports amplifies self-doubt, performance anxiety, and the fear of underperforming upon return to competition. Monsma and Mensch (2009) suggest that athletes with short-term injuries are more likely to use cognitive imagery of their sport more positively and more frequently during recovery, which may indicate that short-term injuries are better at coping with mental imagery of past injuries.

Somatic Trait Anxiety

Although long-term athletes showed elevated Somatic Trait Anxiety (19.76 vs. 18.00), this difference was less significant (+9.8%) than the disparity in Cognitive Worry. The psychological burden of prolonged injury—manifested by self-doubt, intrusive thoughts, and performance anxiety—appears to be a more significant inhibitor than the resulting physiological nervous symptoms, which include muscle tension, elevated heart rate, and heightened arousal. Statistical analysis further supports this, as the independent-samples t-test yielded a p-value of 0.403, indicating the difference between the groups was not statistically significant. Additionally, the effect size for Somatic Trait Anxiety was categorized as small (Cohen's $d = 0.29$). According to Monsma and Mensch (2009), when placed in an imagery program for mental recovery, athletes with longer injury duration were less likely to use imagery and more likely to experience some form of somatic anxiety. Nevertheless, there was still only a relatively minor somatic difference, which implies that physical anxiety symptoms may reach a stable point or plateau regardless of the injury duration.

Concentration Disruption

An athlete's ability to concentrate during competition does not appear to be influenced by injury duration. Both the athletes who recovered in under or over three weeks reported nearly identical levels of difficulty focusing while playing. The short-term injury group yielded a mean score of 9.47, and the long-term injury group scored 9.35. This microscopic difference of -0.12 points, alongside similar standard deviations, indicates highly consistent responses across both groups. This finding stands as a notable anomaly, diverging completely from the upward trend observed in the other psychological inhibitors measured. This could imply that concentration is inherently situational: while long-term athletes noted pervasive fears outside of play, the sport's immediate cognitive demands may force an athlete into a state of focus once he/she returns to play. Statistical analysis confirms this lack of impact, yielding a p-value of 0.921 and a negligible effect size (Cohen's $d = -0.03$). For practitioners, this means that while long-term injured athletes may need structured support to rebuild confidence, they may not require targeted interventions for focus or concentration disruptions upon returning to play. Van der Sluis et al. (1998) found that while cognitive complaints like fatigue (49%) and slowness (44%) remain highly prevalent years after an injury, concentration disruption is reported less frequently (36%). This suggests that concentration is indeed more resilient or situational compared to the "pervasive fears" (worry) that haunt athletes outside of play.

Open-Ended Qualitative Analysis

Fear and psychological readiness

In plain terms, short-term athletes view fear as a situational barrier, often triggered only by "aggressive players" or a "close call" during play. They define their readiness almost exclusively by the absence of physical pain. Conversely, athletes recovering from long-term injuries describe pervasive, intense fears, with one participant explicitly stating they experience "PTSD of getting injured again" every time they step on the court. Research confirms that psychological readiness often lags behind physical recovery. For these long-term athletes, "readiness" is frequently hindered by kinesiophobia—an irrational and debilitating fear of movement or re-injury—that persists even after functional strength and range of motion are restored (Pasqualini, 2025). In summary, their true readiness requires psychological stability, in which they must learn to trust their bodies again and overcome the mental hurdle that accompanies physical healing.

Confidence and Anxiety

Short-term injured athletes generally treat their physical setbacks as routine, experiencing brief, self-resolving drops in confidence; they note that thoughts of feeling "weaker and slower" tend to quickly "fade off" as they return to consistent practice. Long-term athletes, however, report profound feelings of vulnerability and identity disruption, stating the injury caused them to lose "all motivation" and realize their body is "very fragile" rather than "unstoppable". According to Monsma and Mensch (2009), duration injury might not be the major predicament of somatic symptoms, but a largely contributing factor is an athlete's ability of "self-efficacy". Evidence indicates that an athlete's confidence in returning to their pre-injury skill level is a much stronger predictor of somatic anxiety than the actual number of days injured, suggesting both groups may have stabilized to their perceived efficacy, which in turn regulates their physiological symptoms.

Coping and Mindset Progression

When examining coping mechanisms, the data show that short-term athletes rely on informal, intuitive strategies like listening to music, talking to friends, or simply "eating and not thinking about it". This results in very modest, subtle changes to their overall mindset, mostly just realizing they need to warm up properly, both mentally and physically. Research by Monsma et al. (2009) supports the idea that athletes often deal with their mindset intuitively. Their study found that the majority of injured athletes used mental imagery without any formal training, describing this as "prototypical imagery use". In contrast, long-term athletes are forced to adopt deliberate, highly structured approaches to rehabilitation. They undergo a transformative psychological arc, often starting out "frustrated, scared,

and impatient" before learning to adopt a mindset of "acceptance" and "trusting the process". This confounding emotional navigation occurs despite high school athletes largely lacking access to structured psychological support. The isolation of this recovery process is evident in striking outliers, such as one long-term athlete who felt no coping strategy worked except waiting for the anxiety to pass, or another who remained stuck in a state of feeling "always in pain". Thus, it is more helpful and practical for long-term injury athletes, according to Schwab Reese et al. (2012), should have more structured interventions like Acceptance and Commitment Therapy (ACT) or guided imagery to manage intense re-injury anxiety and "psychological consequences".

CONCLUSION

This study investigates the extent to which injury duration affects performance-related anxiety during high school athletes' return to sport. The hypothesis that athletes sidelined for three or more weeks should report significantly higher anxiety and psychological barriers was partially supported. While the quantitative differences did not reach statistical significance, long-term injured athletes demonstrated a practically meaningful increase in cognitive worry and a slight elevation in somatic anxiety, though concentration disruption remained notably unchanged. In contrast, the open-ended qualitative questions revealed that results were substantially different: long-term athletes reported persistent re-injury fears, severe identity disruption, and complex psychological needs, contrasting sharply with the fleeting, self-resolving doubts that short-term injury athletes had. Ultimately, these findings reveal that extended absences can significantly intensify internal mental distress. The core implication is that standard physical medical clearance is insufficient for long-term injuries. High school sports programs must integrate structured psychological assessments and mentorship protocols to ensure athletes are mentally, not just physically, prepared to safely return to competition.

EVALUATION/LIMITATIONS

While this study provides robust evidence on how psychological inhibitors affect returning athletes with varying injury durations, several methodological limitations must be acknowledged. The primary strength of this research lies in its mixed-methods approach. Complementing the validated SAS-2 instrument with open-ended qualitative responses enabled a highly refined understanding of athletes' mental experiences that quantitative responses alone could not provide. In addition, the exact 1:1 ratio between the short-term and long-term injury group size ($n = 17$ each) ensured a balanced comparative framework. However, the study's small sample size ($n = 34$) severely restricted statistical power, which highly contributed to the lack of statistical significance ($p < 0.05$) despite observing a practically meaningful effect size in cognitive worry scores. Methodologically, the cross-sectional design and reliance on retrospective self-reporting introduce potential recall bias and preclude tracking of true psychological dynamics over the full recovery period. Additionally, the absence of pre-injury baseline anxiety measurements makes it difficult to definitively isolate injury-induced anxiety from an athlete's previous trait anxiety.

To further strengthen future research, study designs should transition to a longitudinal structure, first capturing baseline anxiety immediately upon injury and measuring at each defined, standardized milestone throughout the return-to-sport process. Astonishingly, the original focus of this research was to cross-compare the impact of injury duration across different competitive levels in sports: high school and professional athletes. Due to the limited reach and exceptionally low response rate among professional athletes, this original approach was abandoned, as continuing would have yielded even more statistically unreliable comparisons. Future studies should actively pursue this multi-tier comparison by formally partnering with collegiate athletic departments of professional sports networks to secure a robust, stratified sample of athletes (e.g., $n = 50$ per competitive level and injury classified duration). Alternatively, there could have been a more competitive pool of high school athletes, in which future researchers should target recruitment through sporting conferences and elite international tournaments, such

as SEASAC, IASAS, or APAC. Executing this comparison is critical for evaluating major confounding variables present in the current study. Alongside injury duration, it would have allowed researchers to measure the extent to which access to elite structured resources, such as dedicated sports rehabilitation facilities, mentorship, specialized coaches, and full-time sports therapists, plays an active role in mitigating performance anxiety in sports, compared to the limited support systems available to high school athletes.

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