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Solar-Powered Electric Vehicle Charging Station Enhanced by IoT Integration

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Abstract

This project introduces a solar-powered electric vehicle (EV) charging station that incorporates Internet of Things (IoT) technology to enhance monitoring and operational control. While the integration of solar energy for renewable power generation is promising, the real-time solar voltage monitoring system raises questions about the overall efficiency and reliability of solar energy under variable environmental conditions. The automatic detection of a vehicle's position over the wireless charging coil, eliminating manual intervention, presents a convenient feature, though it may rely heavily on precise alignment, potentially limiting user-friendliness in real-world settings. The reliance on the Blynk IoT app for remote monitoring and control of the charging session introduces both opportunities and challenges. On one hand, it offers users the ability to track charging progress and battery levels from a distance, fostering a sense of control. On the other hand, it raises concerns regarding the app's security, data privacy, and the potential for connectivity issues, which could disrupt the charging experience. Furthermore, the adjustment of charging parameters based on solar power availability demonstrates an attempt to optimize energy usage, but the system's adaptability to sudden fluctuations in solar energy generation could be more rigorously evaluated to assess its practicality. While the system's design strives to reduce grid dependency and promote eco-friendly transportation, the impact of such a solution on the wider infrastructure remains unclear. The project's value proposition of combining solar energy with IoT technology is undeniably innovative, yet its real-world application and scalability require deeper scrutiny to ensure that it provides a genuinely sustainable and seamless experience for EV owners.

Keywords: IoT, sensors, monitoring, solar, wireless charging

INTRODUCTION

The growing adoption of electric vehicles (EVs) as a sustainable mode of transportation undoubtedly calls for the development of more efficient and eco-friendly charging infrastructures. However, traditional EV charging stations remain heavily reliant on grid power, which is not always the most environmentally conscious source of energy. In response, solar-powered EV charging stations have been presented as a promising alternative, leveraging renewable solar energy to charge electric vehicles. While this approach has the potential to reduce the carbon footprint and foster a more sustainable energy ecosystem, it is important to critically assess the feasibility and reliability of such systems under varying environmental conditions, as solar energy is inherently intermittent and location-dependent [1–5].

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The proposed integration of advanced technologies such as the Internet of Things (IoT) to enhance the functionality and convenience of solar-powered charging stations further complicates the sustainability narrative. Although IoT offers the potential for real-time monitoring and control, there are concerns regarding the reliability of the technology and potential security risks associated with IoT-enabled devices [6–10]. The constant measurement and adjustment of solar voltage, although well-intended, may not address the unpredictable nature of solar energy generation, which could compromise the efficiency of the charging system in regions with less consistent sunlight. Moreover, the automatic detection of vehicle positioning over a wireless charging coil, although convenient, raises questions regarding the accuracy of this mechanism, as misalignment or interference could disrupt the charging process.

The reliance on the Blynk IoT app to provide vehicle status updates and energy consumption data raises additional concerns about data privacy, app functionality, and potential connectivity issues that could disrupt user experience. Although the integration of solar power and IoT promises a more energy-efficient and seamless charging experience, the practicality and scalability of this system need to be scrutinized, particularly in terms of long-term maintenance, infrastructure costs, and real-world usability across diverse environments [11–15].

In summary, although the combination of solar energy and IoT presents an innovative approach to EV charging, the implementation and reliability of such systems remain uncertain. These advancements may not fully address the challenges of energy variability, technology reliability, and user accessibility, which are crucial factors for ensuring widespread adoption and true sustainability in the EV charging infrastructure.

LITERATURE SURVEY

Elzalet et al. (2019) in the paper titled "*Charging Station for Electric Vehicles Using Solar with IoT*" discuss the design of a solar-powered EV charging system enhanced by IoT technology. The system aims to optimize the use of solar energy through a Maximum Power Point Tracking (MPPT) controller that monitors and ensures the generation of maximum power from the solar panels. The simulation of the setup was executed using Proteus software, and the system was controlled using an Arduino UNO R3 board. Key parameters, including the battery status, amount of power generated, and energy distribution, are displayed on an LCD screen [1]. In addition, a GSM modem is incorporated into the system to send alerts if there is a drop in power, thereby enhancing the monitoring and maintenance of the system. A web-based interface is also implemented, allowing users to check the charging station's status, track the power transferred to the vehicle, and find the location of the available charging stations. The primary goal of this study is to contribute to the reduction of greenhouse gas emissions and dependence on fossil fuels, aligning with global efforts to promote sustainable energy solutions for EVs [16–21]. However, the feasibility and scalability of such a system in various environmental and operational contexts require further examination, particularly regarding the reliability of IoT components and the system's response to fluctuating solar energy availability.

Kumaran et al. (2023) in the paper titled *"Designing and Testing of Renewable Energy-Based Electric Vehicle with GSM Technology"* address the design of a prototype EV powered by renewable energy sources, specifically solar power, for individuals with physical disabilities. The project emphasizes the need for a vehicle that can be operated by those with impairments, such as limited mobility in their legs or arms, which conventional vehicles cannot accommodate. This innovation aims to enhance the independence of people with disabilities by providing them with the ability to drive without relying on others [2]. This study highlights the growing concern over sustainable mobility, with particular attention paid to the environmental impacts of traditional automotive systems. The widespread use of vehicles has significant implications on carbon dioxide emissions, climate change (global warming), and fuel depletion. By adopting renewable energy sources, such as solar power, this project presents a solution that is not only environmentally friendly but also pollution-free, eliminating the emission of greenhouse gases. This approach aligns with broader sustainability goals, contributing to a cleaner and greener future by reducing the environmental footprint of transportation [22–28]. While this concept is promising, the practical implementation of solar-powered vehicles for individuals with disabilities requires careful consideration of factors such as energy storage, vehicle performance, and cost-effectiveness. Additionally, the integration of GSM technology for remote monitoring and communication adds a layer of functionality, but the system's reliability and accessibility in real-world scenarios must be thoroughly tested to ensure its viability.

Gayathri et al. (2021) in the paper titled *"Solar Based Charging Station for Electric Vehicle"* discuss the design and functionality of a solar-powered charging station for EVs. An EV charging station, also known as Electric Vehicle Supply Equipment (EVSE), serves as a point where electric vehicles can be recharged. This study primarily focuses on optimizing the performance of the solar panels used in these charging stations by dynamically adjusting their tilt angle to maximize power generation based on the intensity of sunlight [3]. The system incorporates IoT technology to continuously monitor and manage the power available in the charging station, both locally and remotely. Through IoT integration, the status of the charging process and energy generation can be tracked in real time, enhancing efficiency and user experience. This approach aims to make the charging station more efficient and responsive, leveraging solar energy in a way that reduces dependence on grid power and promotes sustainability [29–34]. However, while this study proposes a valuable solution to improve the energy efficiency of solar-powered EV charging stations, it is essential to evaluate the practicality of implementing such dynamic solar tracking systems in various environments, considering factors such as maintenance, weather conditions, and the cost-benefit ratio of adding IoT functionality. The scalability and reliability of these systems in real-world applications require further investigation to ensure their long-term viability.

Atsushi et al. (2021) in the paper titled *"Energy Management System Optimization of Drug Store Electric Vehicles Charging Station Operation"* address the growing demand for EV charging stations driven by the increasing adoption of electric vehicles over traditional combustion engine vehicles. This highlights the necessity for efficient energy management in the operation of these stations, particularly in the context of integrating renewable energy sources, such as photovoltaic (PV) power generation [4]. A key aspect of this study is the proposal to establish EV charging stations at convenience stores to optimize the use of excess photovoltaic energy generated by households. By collecting and distributing this surplus solar power, the stations can help alleviate grid pressure while providing a sustainable source of energy for EVs. This model offers the potential to market unused solar energy to EVs, creating a symbiotic relationship between residential solar power generation and charging infrastructure. Although the concept of integrating PV energy with EV charging stations is promising, practical challenges need to be addressed, such as the efficiency of energy transfer, storage, and distribution between the two locations [35–41]. Additionally, concerns regarding the financial viability, regulatory considerations, and scalability of such a system require further exploration. The long-term impact of this model on the grid and the associated feed-in tariff reductions requires in-depth analysis to ensure that it provides both economic and environmental benefits.

SYSTEM REQUIREMENT

Required Hardware

- ESP8266 NodeMCU Board
- NE555 Timer IC
- IR Sensors
- Coils
- OLED Display
- Zero PCB Board
- Power Supply
- IRF540 N-Channel MOSFET

- Relay
- Solar Panel
- LM7805 Voltage Regulator
- Screw Terminals

System design diagram: Figure 1 shows the system design of a solar-powered EV charging station enhanced by IoT integration.

Electrical circuit layout: Figure 2 shows the electrical circuit layout of a solar-powered EV charging station enhanced by IoT integration.

PROPOSED METHODOLOGY

Solar Power System

The initial phase involves the installation of high-efficiency solar panels to harness solar energy and convert it to electrical power. To optimize energy utilization, a voltage monitoring system should be implemented to track and measure the energy output of solar panels in real time. This system ensures that the charging process is dynamically adjusted based on the available solar power to improve efficiency. Furthermore, a battery storage system is essential for storing the excess energy produced during peak sunlight hours. This stored energy acts as a buffer, enabling the charging station to continue functioning during periods of low solar generation, such as cloudy days or nighttime, thereby ensuring consistent operation and reducing reliance on external power sources [42–48].

Wireless Charging Technology

Use a wireless charging pad for EV. This involves setting up a coil in the parking space, where the vehicle can automatically align with a corresponding coil in the ground. The system should be designed such that the charging process starts automatically when the vehicle is correctly positioned, making it more convenient for users by eliminating the need for physical plugs or cables [49].

IoT Integration

An ESP8266 Wi-Fi module was used to connect the charging station to the internet. This allows the system to send real-time data about the solar energy being generated, the vehicle's charging status, and any issues to a mobile app, such as Blynk.

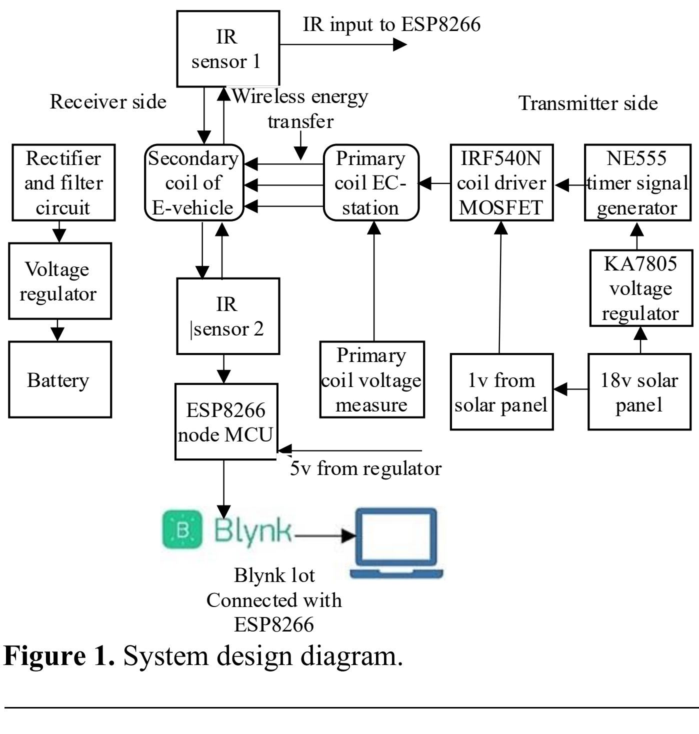

Figure 1. System design diagram.

Users can monitor the charging process from anywhere, receive notifications, and even remotely control certain settings. This will make the charging experience more user-friendly and allow for better management of the energy usage [50].

Project Model

Figures 3 and 4 demonstrate the final model of a solar-powered EV charging station enhanced by IoT integration.

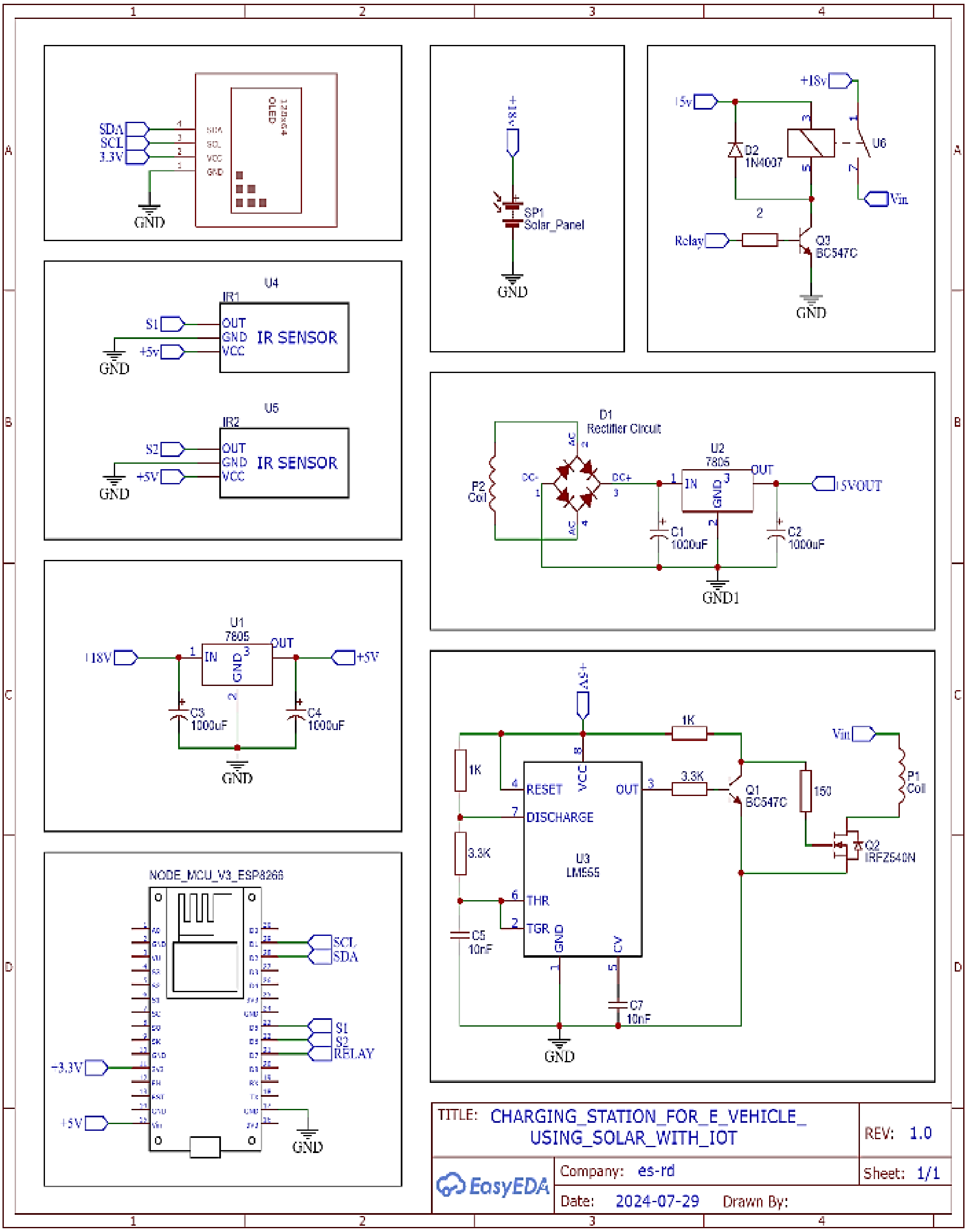

Figure 2. Electrical circuit layout.

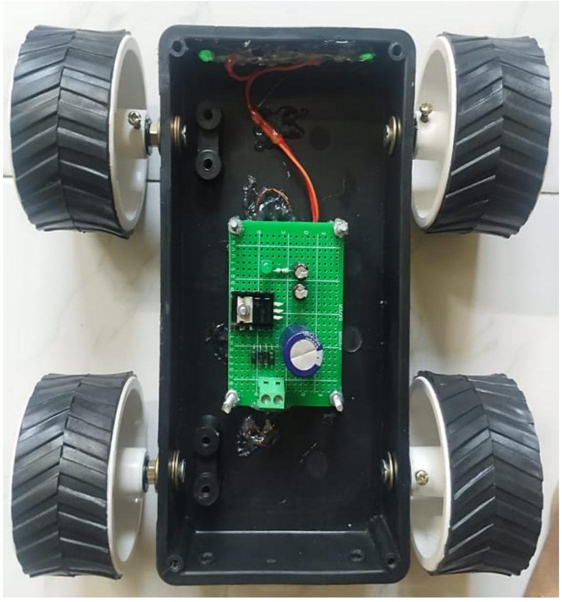

Figure 3. Final project.

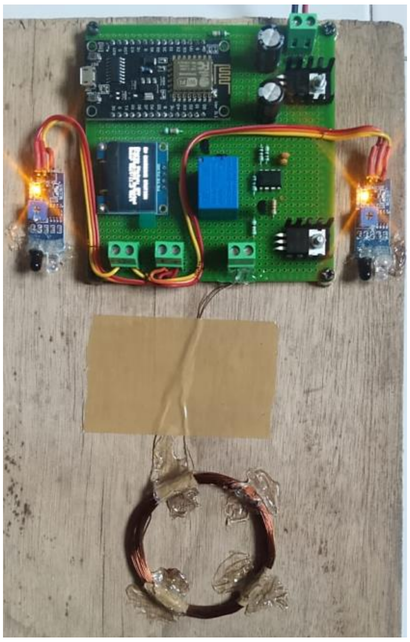

Figure 4. Final hardware.

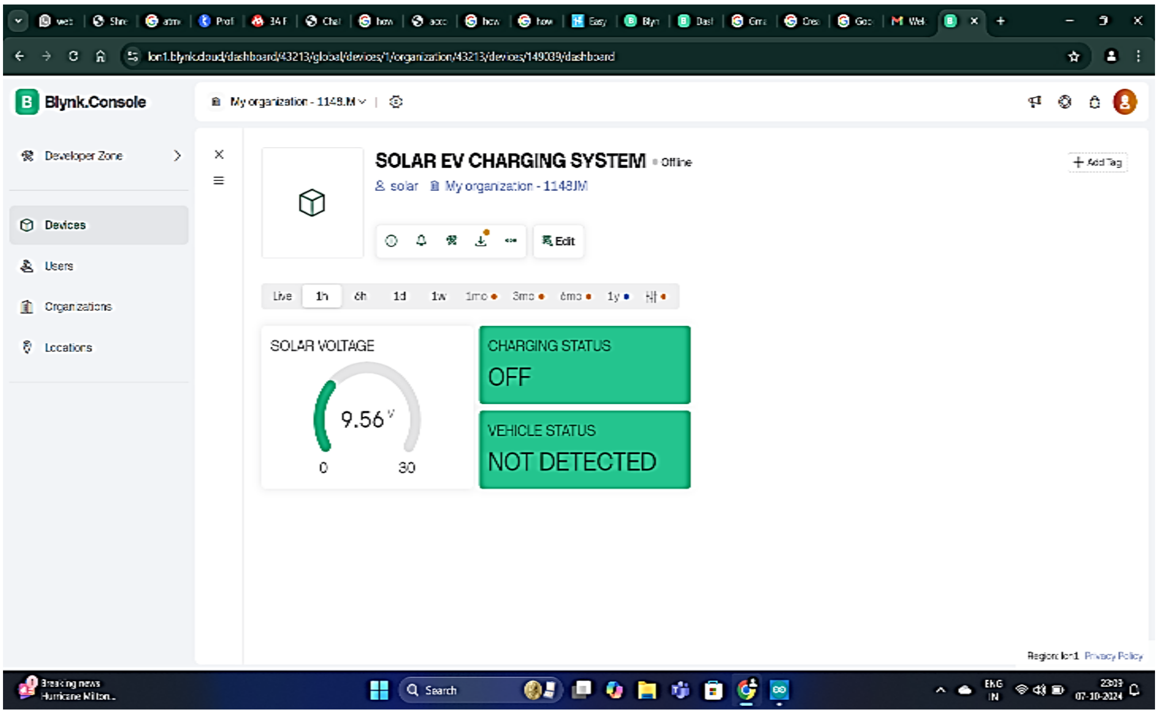

Figure 5. Blynk result.

RESULT

The system works by using solar panels to generate electricity from sunlight, which is then stored in a battery or used directly for charging EVs. When an EV is parked over the wireless charging pad, a sensor detects the presence of the vehicle and automatically starts the charging process without the need for cables. The ESP8266 Wi-Fi module connects the charging station to the internet, allowing real-time monitoring and control via the Blynk IoT app. Through the app, users can check solar power generation, see the charging status of their vehicle, and receive notifications about the charging process Figure 5. The system adjusts to the available solar energy, ensuring efficient use of power while minimizing reliance on the grid.

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CONCLUSION

In conclusion, this project effectively illustrates the integration of solar power and IoT technology to develop a highly efficient, sustainable, and user-friendly EV charging station. By harnessing solar energy, the system reduces its reliance on conventional grid power, significantly decreasing the carbon footprint associated with EV charging. The incorporation of a solar voltage monitoring system ensures that the available solar energy is optimally utilized, contributing to the overall energy efficiency and environmental sustainability of the system. Furthermore, the adoption of wireless charging technology eliminates the need for physical connections, thereby providing a seamless and convenient charging experience for users.

The ESP8266 Wi-Fi module plays a critical role in the IoT integration of this system, facilitating real-time communication between the charging station and the users' smartphones. Through the *Blynk IoT app,* users can remotely monitor the charging status of their vehicles, track solar power utilization, and receive real-time notifications regarding the charging process. This IoT-enabled feature not only enhances convenience for users but also provides valuable operational data for both consumers and charging station operators. Additionally, the system's automatic detection of an EV placed on the charging coil ensures that the charging process begins without the need for manual intervention, further improving user experience. Figures 1, 2, and 3 show the final results of the proposed system.

Looking ahead, this solar-powered IoT-integrated EV charging station could be further enhanced with features such as *dynamic charging adjustments* based on weather conditions, expanded *energy storage* capabilities, and the integration of additional *renewable energy sources.* Moreover, ongoing advancements in *wireless charging technology* can significantly enhance the performance of the system, reduce charging times, and improve efficiency. Ultimately, this project underscores the potential of combining *renewable energy* with IoT to create a smarter, more sustainable charging infrastructure that addresses the growing demands of the EV market while supporting *environmental preservation*.

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Author Contributions Statement

All authors contributed significantly to the research and preparation of this manuscript.

Conflict of Interest Statement

All authors declare no conflicts of interest.

Informed Consent

Informed consent was obtained from all individual participants included in this study.

Ethical Approval

This study did not involve any human or animal subjects; therefore, ethical approval was not required.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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