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Research Article

Development of an industrial motor controls trainer

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Abstract:

The increasing demand for highly skilled technical professionals highlights the need for innovative educational tools that effectively bridge the gap between theoretical instruction and practical application. This study aims to develop a cost-efficient, industry-aligned industrial motor control trainer to improve hands-on learning in technical education. The trainer integrates industry-standard components, accommodates single-phase and three-phase power configurations, and features built-in simulated faults to facilitate troubleshooting exercises. A descriptive-developmental research methodology was employed, utilizing validated surveys. The data was collected from students, faculty members, and licensed electrical practitioners. The findings revealed a high level of acceptability across multiple criteria, including cost-effectiveness, safety, construction quality, functionality, and educational relevance. Results indicate that the developed trainer serves as an effective instructional tool, significantly enhancing students' comprehension of motor control circuits. Based on these findings, the study recommends the implementation of the trainer in technical schools and vocational institutions, along with further enhancements such as the integration of programmable logic controllers and potential mass production to increase accessibility. This research contributes to the advancement of technical education and workforce development, aligning with Industry 4.0 standards.

1. Introduction

The demand for skilled technical workers continues to grow globally, particularly in industries such as construction, maritime operations, and advanced manufacturing. Filipinos, recognized for their diligence and competence, play a vital role in these sectors, highlighting the importance of effective technical education programs to equip students with essential skills.

At Isabela State University’s Angadanan Campus, its technology program aims to produce graduates proficient in technical repair work and entrepreneurial skills, contributing to the skilled workforce from northeastern Luzon. However, a significant gap exists in the availability of industry-relevant training equipment, particularly for electrical trades. Commercially available training equipment is prohibitively expensive and often sourced internationally, exceeding the budgetary limitations of the institution.

This study seeks to address this challenge by developing a cost-effective, customized industrial motor controls trainer. The trainer is designed to enhance students' understanding of motor control circuits while aligning with the institution’s curriculum and industry requirements. Furthermore, the trainer integrates modern, state-of-the-art components, offering a practical solution that prepares students for real-world applications, including those aligned with Sustainable Development Goals (SDG) 4: Quality Education and SDG 9: Industry, Innovation, and Infrastructure.

Objectives of the Study

This study aims to develop and validate a portable industrial motor control trainer to facilitate hands-on learning for students. Specifically, it seeks to:

1. Develop a training equipment for motor controls;
2. Evaluate the acceptability of the trainer as an instructional tool based on the evaluations of teachers, students, administrators, and industry experts;
3. Assess the trainer’s cost-effectiveness compared to commercially available equipment; and
4. Identify core concepts and applications for training activities using the trainer.

Scope and Delimitations

The developed trainer focuses on mastering motor control technologies using components such as magnetic contactors and electromechanical relays. It supports both single-phase and three-phase power configurations and is suitable for indoor and outdoor training. The trainer's modular design allows easy wiring and adaptability for various circuit configurations, excluding digital controllers or programmable logic systems, although integration is feasible in future iterations.

Significance of the Study

1. People. The study has a direct impact on several groups of individuals. The equipment provides hands-on learning opportunities, nurturing students' technical skills critical for employment and certification in electrical installation and maintenance. It also empowers faculty members with effective tools to demonstrate complex motor control systems, improving teaching efficiency and outcomes. Furthermore, the trainer contributes to upskilling technical workers, preparing them for Industry 4.0/5.0 technologies.

2. Places. The trainer may serve as a state-of-the-art teaching tool, improving technical education quality at ISU, other schools, colleges, and training centers. It also bridges the gap between academic training and real-world applications, ensuring that graduates meet workplace demands. Moreover, its cost-effectiveness makes it viable for implementation in developing regions, promoting equitable access to advanced technical education.

3. Policies. This study aligns with initiatives promoting STEM (Science, Technology, Engineering, and Math) education, technical-vocational education, and lifelong learning in line with SDG 4 (Quality Education). Importantly, it addresses skill gaps highlighted by Technical Education and Skills Development Authority National Certification III (TESDA NC III) requirements, promoting observance of professional certification standards. It also supports policies aimed at encouraging a technically skilled workforce, which is necessary for industrialization and economic development.

4. Patents and Publications. Its design, cost-efficiency, and effectiveness could lead to intellectual property protection, encouraging further R&D and commercialization. Also, the study can result in academic papers or technical manuals detailing the trainer's design, development process, and instructional effectiveness. These resources could guide other researchers and educators in replicating or improving the model.

5. Partnerships. It promotes partnerships with industries and can ensure the trainer remains relevant to emerging technologies and industry requirements. Likewise, support from local or international organizations can facilitate wider adoption and funding for similar initiatives.

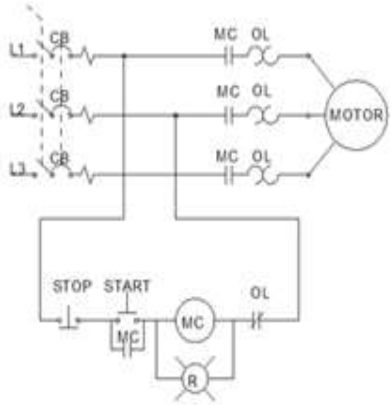
6. Production. The trainer's design may be mass-produced locally, reducing costs and promoting local entrepreneurship. Its production and deployment to schools and training centers contribute to workforce development. Furthermore, the trainer promotes sustainable education practices by reducing dependency on imported, expensive equipment.

Moreover, this research supports Sustainable Development Goals (SDGs) such as SDG 4-Quality Education. By promoting technological skills, the trainer promotes equitable, high-quality education; SDG 9-Industry, Innovation, and Infrastructure. By developing innovative educational tools, the study strengthens educational settings.

Conceptual Framework

This research utilizes the Input-Process-Output (IPO) Model. Inputs include technical information from expert interviews, CHED policies, guidelines, and standards, curriculum requirements, TESDA NC III standards, and a review of literature and related studies. In the process stage, locally sourced materials such as Formica boards, aluminum bars, contactors, and were used, likewise two (2) single-phase electric motors were rewound into three-phase electric motors to match the size and requirements of the trainer. A validated questionnaire was floated to the respondents for the acceptability level of the trainer. The data were analyzed and interpreted. The output of the study is a functional, portable industrial motor control trainer suitable for various training environments.

Figure 1. *Pictorial views during the planning, preparation, and development stages of the trainer*



Figures 2. *Start-stop power and control circuit diagram for testing three-phase motors,*

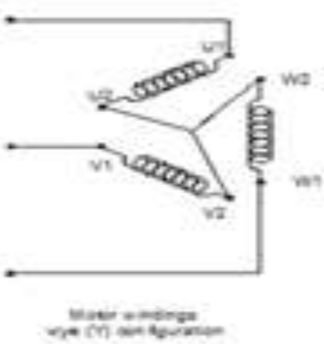


Figure 3. *the wye-connected winding*

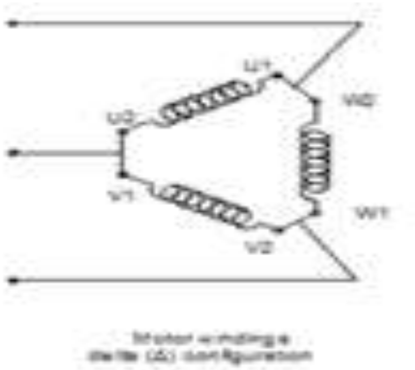


Figure 4. *the delta-connected, six-lead, three-phase motor.*

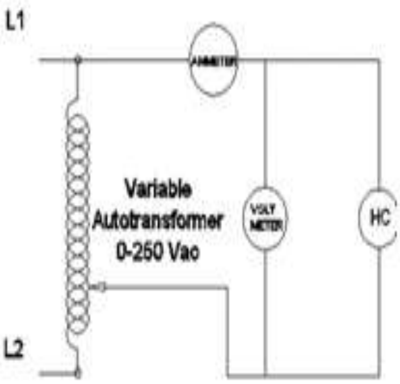


Figure 5. *The diagram for Holding Coil (HC) with Variable Autotransformer*

Table 1. *Fault Location and its Effects*

Switch	Fault Location	Effects
S1	Holding Coil 1	Motor controlled by contactor 1 will not operate
S2	Motor 2 coil Winding	Motor 2 winding is open-circuited
S3	Motor 1 coil winding	Open magnetic coil/winding
S4	Overload relay 1	Controls the contactors and electric motors

Table 2. *The level of Acceptability using the Likert Scale*

Scale	**Level of Acceptability**
5 points	Highly Acceptable
4 points	Acceptable
3 points	Moderately Acceptable
2 points	Slightly Acceptable
1 point	Not Acceptable At All

Table 3. *The electric motor M1 current data*

Motor M1 with 3 terminals		
Coil/winding	Current	Voltage
Winding A	0.15	220
Winding B	0.12	223
Winding C	0.14	220

Table 4. *The electric motor M2 current data*

Motor M2 with 6 terminals				
Coil/ winding	Y (wye) Connection		∆ (delta) Connection	
	Current	Voltage	Current	Voltage
Winding A	0.13	218	0.86	218
Winding B	0.12	223	0.78	223
Winding C	0.15	220	0.91	220

Figure 6*, The registered Electric Motor Controls Trainer with IPOPhil Utility Model No. 2-2014-000564*

Table 5. *Identified concepts and activities that can be demonstrated by the trainer*

Concepts/Topics	Parts	Functions
1. Components of Power System 2. Operating principles of three phase electric motors 3. Characteristics and applications of AC motors 4. Common AC motor components 5. Motor winding connections and motor controls – (relays and timers) 6. Schematic diagrams and motor control circuits 7. Preventive measures and troubleshooting control circuits including maintenance of AC motors 8. Start – jog connection 9. Start-Stop connection 10. Interlocking Connection 11. Forward Reverse Connection 12. Star Delta Motor Starting 13. Interfacing with microcontrollers and PLC trainers	Three Phase Electric Motors	A motor with a continuous series of three overlapping AC cycles offset by 120 degrees. Three-phase power is used for all large AC motors and is the standard power supply that enters factories.
	Magnetic Contactors	Are used to control electric motors, lighting, heating, capacitor banks, and other electrical loads. It has three components. These include power contacts, auxiliary contacts, and the electromagnet that provides the driving force to close the contacts.
	Overload Relays	**Relays** that rely on heat produced by the motor current to operate a bimetal contact or release a contact held closed by a low-melting-point alloy. The overload relay opens a set of contacts. The heaters can be matched to the motor so that the motor is protected against overload.
	Timer Relays	Are relays that close or open contacts when it reaches its pre-set time.
	Circuit Breakers	a device designed to open and close a circuit by non automatic means and to open the circuit automatically on a predetermined over current without damage to itself when properly applied within its rating.
	Push button switches	Small buttons or knobs that when pushed operate something especially by closing an electric circuit. Are switches intended for starting large motors. These switches are normally open (ON) or normally closed (OFF).

2. Review of Related Literature

Electric motors and controllers are vital components in industrial and household applications, transforming electrical energy into mechanical energy and enabling the automation of numerous processes. Technologies such as relays, contactors, and starters are central to motor control systems, ensuring safe and efficient operation.

Modern educational practices emphasize the importance of high-quality instructional materials, which, according to studies [1], can significantly impact student achievement. Effective materials align with curriculum goals and promote hands-on learning, as supported by Dale's Cone of Experience, which highlights the superior retention achieved through active participation.

Accordingly, instructional materials should be a product of educational research, emphasizing experiential learning and addressing prior knowledge. They also emphasized that higher student achievement is associated with medium to high fidelity in using an instructional model [2].

Review of Related Studies

Research underscores the value of customized training tools in technical education. For [3], and other studies have validated the acceptability of training materials based on criteria such as cost, functionality, and reliability. [4] emphasized the importance of aligning materials with learner needs, while [5] advocated for the development of sophisticated, relevant equipment to bridge the gap between educational outputs and industry demands.

This study addresses the inadequacy of equipment in technical education and contributes to the goals of Education 4.0/5.0 and Industry 4.0/5.0. The trainer raises technological literacy, supports cooperative education models, and prepares learners for roles in modern, technology-driven industries. The integration of Industry 4.0 technologies with Education 4.0 is transforming traditional educational systems to prepare students for the challenges of the digital age [6,7]. This new educational model focuses on developing students' problem-solving skills, individual abilities, and STEM competencies necessary for the fourth industrial revolution [6,7]. Education 4.0 employs advanced technologies such as augmented reality, virtual reality, and the Internet of Things to enhance learning experiences, particularly in higher education [8]. These technologies facilitate immersive content delivery, student engagement, and simulation of real work scenarios, while also developing soft skills and technological literacy [8]. The integration of Education 4.0 and Industry 4.0 technologies is crucial for preparing future engineers and researchers in data-driven fields, as demonstrated through case studies in remote engineering and remote labs [9]. In summary of the literature, the development of an industrial motor controls trainer represents a significant advancement in technical education. It addresses equipment shortages, aligns with curriculum standards, and prepares students for modern industry demands while contributing to broader goals of sustainable development and educational innovation. This study provides a framework for integrating practical training tools into technical education programs, making the way for further research and development in this field.

Project Design and Considerations

The study began with selecting and purchasing locally available materials, followed by constructing the model based on a detailed arrangement of components and instruments. The researcher identified the specific skills to be developed using the trainer, guided by the TESDA Competency Standards and the CHED-approved course guide. A training module was also created in alignment with the trainer's configuration to support laboratory activities. These activities tested the equipment's reliability and functionality.

Construction of the Trainer's Base

The electrical controls were securely enclosed in a marine plywood box to prevent grounding issues. This figure served as a guide, illustrating the construction process with labeled components.
Details about the materials, electrical accessories, and financial requirements are documented.

Operation and Testing of Electric Motors

The completed model underwent technical evaluation, including resistance, current, and voltage testing, as well as functional tests of motor control circuits. A manual of operation and safety reminders was provided for the trainees.

Testing Procedures

A. Electric Motors

Two (2) three-phase motors were developed and tested. These motors came from a conventional stand fan motor assembly or frame.
It is rewound and transformed into three-phase windings for instructional purposes. Considering the diagrams of start/stop, wye, and delta connections, voltage and current measurements were recorded.

B. Magnetic Contactors

The operating characteristics of four magnetic contactors were tested using a variable autotransformer (Figure 5). Pull-in, drop-out, nominal, and inrush current values were measured and recorded.

The Simulated Faults

To enable troubleshooting exercises, the trainer includes switches that simulate faults. When pressed, these switches disrupt normal circuit operation, challenging students to locate and correct the issues. Below is a list of the faults simulated by each switch and their corresponding effects.

Evaluation Procedure and Criteria

The trainer's acceptability was evaluated using a validated descriptive questionnaire. Respondents rated the trainer based on its components, arrangement, and safety features using a five-point Likert scale

Research Sampling, Tools, and Techniques

Purposive sampling was employed to select respondents, who included Twenty (20) electricity majors for high school and college students, Ten (10) electrical technology faculty members, and TESDA specialist, and Twelve (12) licensed electrical practitioners (LEP) such as electrical engineers (10), electrical contractor (1), and OFW (1) which specialized in motor controls. Since the respondents' perceptions were rated in terms of acceptability level, statistical modes were used to compare respondents' evaluations [10].

3. Results and Interpretation of Data

The Training Equipment

Usually, demonstration trainers come in different styles and packaging, it is customized according to one's preference. The skeletal or base upon which instruments can be attached has a major role in the aesthetic and economic aspects of the whole trainer. Apart from this, the arrangement and selection of components have to do with the effectiveness and relevance of the training to be conducted. Also, the trainer is designed for indoor use, and it was manufactured using simple and ordinary equipment at a minimal cost compared to other trainers that function the same. Its boxed type enclosure is stable with excellent electrical insulation material, readily safe to contain sophisticated electrical and/or electronics training materials. This box is covered with a formica sheet that could serve as a whiteboard for a lecture before hands-on activities. This feature enables in situ training without the need for a blackboard for the lecture. The trainer is equipped with a voltmeter to monitor voltage flow that can be used for testing potential difference. This added feature can quickly monitor the presence of electric power to be aware that the student should be cautious in their movement and presence of mind is necessary. Another feature is the presence of a circuit breaker to safeguard the circuit and equipment in case of a short circuit connection.

Electric Motor Test Results

Two (2) three-phase laboratory shop rewinded electric motors were used for this purpose; one motor (M1) is intended for across-the-line starting and has three (3) terminals, and another motor (M2) is for wye-delta starting and has six (6) terminals. The voltage and current obtained were shown for each electric motor in the table 3,4. The winding of motor M1 is internally and permanently connected in a wye configuration for safety reasons during the starting period. When motor M1 was connected across the line, although there was a slight variation in line voltages, it drew almost equal line currents. These differences in current are not sufficient to generate excessive heat that may damage its windings for a long time running period. This claim was confirmed when the unit ran for thirty (30) minutes with only a slight buildup in temperature. The motor M2 unit was also tested and yielded the following current results as noted in Table 4. Since the size of the base, magnet wires, and number of turns for the windings of the two electric motors are identical, this yielded almost the same result when connected in wye configuration. When the windings were wired for delta configuration, their line current was approximately four times their initial values. This accounts for the unsymmetrical winding arrangement due to a limited number of slots intended only for single-phase winding. Using the same connection, there is moderate temperature buildup in the windings. Nevertheless, the motor can continuously operate for fifteen minutes, enough for experimental purpose that needs only two (2) minutes of operation to complete a demonstration, reading and recording activities.As compared to other trainers having three-phase motors, the model has much less consumption, having only 0.91 Amperes as the highest current, as compared to 2 Amperes at most for laboratory purposes.

Acceptability of the Motor Controls Trainer

The table summarizes survey responses on various aspects of a motor controls trainer by presenting, for each indicator, three key statistics from four respondent groups (high school students, and college students, electrical instructors/professors, and licensed electrical practitioners). These key statistics are the mode, frequency, and percentages. The mode is used to describe the most common response rating given by respondents for a Likert scale from 1 to 5. The frequency denotes the number of respondents who selected that mode rating, and the percentage is the proportion of respondents in each group who also selected that mode rating.

Survey Results

The survey is divided into several thematic areas, such as:

1. **Economy.** It evaluates aspects like cost savings and economic gains in design/labor.
2. **Aesthetic**. It focuses on the visual appeal, such as compartment setup, panel color appeal, etc.
3. **Construction**. It assesses build quality, ease of preparation for demonstrations, and component organization.
4. **Function and Safety**. It considers the trainer's operational capability and safety features.
5. **Relevance.** It pertains to looks at the educational impact and practical relevance for learning control circuits.

Each indicator within these sections lists four sets of statistics corresponding to the four respondent groups. In this table, nearly every indicator shows a mode of 5. It suggests that most respondents rated these features at the highest level, reflecting strong overall approval of the trainer's attributes.

Gathered Respondents' Perception per Thematic Area

1. Economy

Cost Savings in Materials and Economic Gains in Design and Labor are rated with a mode of 5 across all groups. The high school students show 90% (9 out of 10 respondents) rating cost savings as 5, while licensed electrical practitioners show 80% for the same indicator. It implies that most respondents **agree** that the trainer is economical, though there is a slight variation in consensus between groups.

2. Aesthetic

Items like "It has an attractive compartment set-up" and "The electrical panel has a color appeal" again have a mode of 5. However, for "The component parts are well organized," the licensed electrical practitioners rated it as 4, with only 40% frequency, which suggests that while students find the components' organization very appealing, experienced practitioners may be more serious about its arrangement.

3. Construction

For aspects like "The panel is easy to prepare for demonstration" and "The components are labeled and identified," all groups mostly agree a mode of 5, though the frequency percentages sometimes drop for licensed electrical practitioners for 70% for "easy to prepare for demonstration" indicating a slightly less enthusiastic view.

4. Function & Safety

Items such as "It can be used for basic to complex motor control circuits" and "Warning signs or safety reminders are visible" maintain a high mode of 5 with strong frequencies and percentages, reflecting high confidence in the trainer's functionality and safety. A minor drop in the percentage, such as 50% or 60% in some cases for licensed electrical practitioners, indicates a more measured assessment from those with field experience.

5. Relevance

The statements like "It provides interesting learning experiences" and "It is a good avenue in mastering basic control lessons" also show a high mode of 5 with high frequencies among most groups, though, again, the licensed electrical practitioners sometimes show slightly lower percentages of 80% as compared with other groups having as much as 90% to 100%. These findings are similar to the study of Antonio (2011) that respondents see differently on the variables such as aesthetic, construction, function, safety, and relevance.

In summary, the consistent mode of 5 across nearly all indicators suggests that the overall perception of the motor controls trainer is highly positive among the respondents. The students both in high school and college tend to rate most attributes at the highest level, often achieving 100% agreement on several items. For instructors/professors and licensed electrical practitioners which has still generally positive evaluation, occasionally show lower percentages and even a mode of 4 in specific, which may reflect a more critical evaluation based on practical or academic expectations.

Overall, the table indicates that while all groups recognize the strong points of the trainer, the professionals who might be using or evaluating the trainer in more rigorous situations offer a slightly harder commendation on a few points. This helps in understanding that while the training equipment is highly regarded overall, there might be room for improvement in areas where expert users see potential problems.

Technical Features of the Developed Trainer

Based on the respondents' evaluation, the following technical features were identified:

1**. Cost saving.** The overall construction cost of the machine is just a portion of the cheapest imported trainer of its kind. It is only 20% of the cheapest trainer available on-line.

2. **Genuine parts**. The parts are acquired locally and it was arranged similar to industrial motor controllers, this set up has made the material excellent for actual hands-on activities.

3. **Ease of wiring.** No installation or fastening of the components is required. Wiring connections can be done easily because its electrical parts and accessories are connected to binding posts serving as terminal points. Connection leads with extendable feature are preferred for use to connect different parts of the trainer.

4. **Properly labeled**. A trainee can immediately identify components and accessories of the model. Protective devices, relays, contacts,
switches and schematic diagrams were printed clearly on the instructional panel board.

5. **Built-in simulated faults**. To enhance troubleshooting skills, simulated faults were included. This is to recognize symptoms and common causes of troubles in industrial motor control system.

6. **It is transferable**. The model can be hand carried or transferred to another place. It can be use for in situ extension and training services.

7. **Environment friendly**. The absence of sharp edges, toxic/hazardous materials, or excessive noise makes the trainer friendly to use.

8. **Insulated base**. The trainer is housed using marine plwood. Formica board covered the exterior part of the housing add aesthetic for the trainer and used as white board for in situ training.

9. **Compatibility of Use**. The trainer can be easily interfaced with other controls such as programmable logic controls or microcontrollers, using relays and other gadgets.

Core Concepts and Training Activities

After the motors and their accessories were tested, a series of demonstrations was done to investigate the concepts that could be learned through the model and what possible electrical laboratory experiments could be done. It was found that basic to complex control circuits can be performed. Laboratory experiments were developed for this model to aid the faculty members in performing activities. These topics are enumerated in the table abovew. Based on it, it can ascertain that the utility model could aid in teaching and learning motor controls.

4. Conclusions

From the findings, the following conclusions were drawn:

1. The study successfully developed and evaluated an industrial motor controls trainer designed to enhance hands-on learning for students.

2. The trainer is cost-effective, integrates industry-standard components, and aligns with curriculum requirements, making it a valuable instructional tool for technical education.

3. The evaluation from different respondent groups, including students, instructors, and licensed electrical practitioners, showed high acceptability across factors such as economy, aesthetics, construction, function, safety, and relevance.

4. The study confirms that the trainer provides a practical and effective platform for teaching motor

control circuits, bridging the gap between academic training and industry demands.

Recommendations

Based on the enumerated conclusions, the following recommendations are hereby given:

1. The developed trainer should be adopted by technical institutions, vocational schools, and training centers to improve the practical skills of students in electrical motor control systems.
2. Future enhancement of the trainer should include the integration of programmable logic controllers and microcontrollers to align with Industry 4.0 technologies.
3. Given its cost-effectiveness, the trainer can be mass-produced locally to provide affordable training solutions, especially in developing regions.
4. Workshops and seminars should be conducted to train faculty members and students on maximizing the use of the trainer in instructional activities.
5. Additional studies can focus on optimizing the trainer's features, evaluating its long-term impact on learning outcomes, and exploring digital enhancements such as augmented reality-based learning aids.
6. Partnering with industries can help ensure the trainer remains relevant to emerging technological trends, providing students with industry-aligned skills and knowledge.

These recommendations will help maximize the impact of the developed motor controls trainer and contribute to advancing technical education in line with modern industrial requirements.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
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- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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