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Artificial intelligence and vehicle license plate recognition: A literature review

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Abstract: This study presents a systematic literature review on the application of artificial intelligence (AI) in vehicle license plate recognition, focusing on neural network-based technologies. The primary objective is to identify recent advancements that enhance traffic control automation and road safety. The research methodology involves a structured search and analysis of 90 significant publications selected from databases such as IEEE Xplore, ScienceDirect, Scopus, and DOAJ. Findings indicate that convolutional neural networks (CNNs) and deep learning models play a crucial role in improving recognition accuracy and efficiency, particularly through optimized image processing techniques and convolutional layers. However, challenges persist due to variations in license plate design and adverse environmental conditions affecting system performance. The study highlights the need for continued research on image preprocessing methods to enhance robustness and adaptability. The conclusions emphasize the critical role of AI-driven recognition systems in modern transportation infrastructure, advocating for further integration of advanced neural network architectures. From a practical perspective, these findings contribute to the development of more reliable and efficient vehicle identification systems, with implications for law enforcement, automated tolling, and smart city initiatives.
Keywords: *Artificial intelligence, License plates, Neural network, Recognition, Systematic literature review.*

1. Introduction

Vehicle license plate identification is crucial in various fields, from traffic control to public safety. Traditionally, this process has relied on centralized systems that can be costly and inefficient. In addition, the lack of transparency in transactions and the difficulty in adapting new technologies hinder the improvement of these systems. The systematic literature review has highlighted advanced technologies, such as neural networks, in vehicle license plate identification. Among these technologies, neural networks stand out for their ability to process large amounts of data efficiently and their adaptability to different conditions and environments.

The results of this review highlight several key components used in vehicle license plate identification using neural networks, such as convolution layers, deep learning algorithms, and image processing techniques. These enable the efficient and accurate operation of the vehicle license plate recognition system. The review structure follows a systematic approach: the methodology is described in Section 2, the results are presented in Section 3, the discussion of the findings in Section 4, and the conclusions are given in Section 5. In addition, relevant references are included to support the findings and analysis.

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2. Methodology

A systematic literature review was conducted using an approach focused on Software Engineering research processes [1-4]. The main goal was to provide a complete overview of the field of study and examine the number, types, and results of existing studies to develop a classification scheme and an appropriate structure. Specialists frequently use this approach since it facilitates the creation of knowledge from publications resulting from research processes [5]. Figure 1 shows the stages of the stipulated method.

Figure 1.
RSL structure.
Source: Revelo Sanchez, et al. [6]

According to Kitchenham and Brereton [7]. The reason for conducting a systematic literature review arises from the demand of researchers to comprehensively and impartially synthesize all available information on a specific topic. Conducting an RSL on applied technologies for electric power transactions allows for identifying, analyzing, and compiling the relevant literature related to this topic. These results will be a valid basis to share with the scientific community.

2.1. Research Questions

Formulating research questions is a crucial task in conducting an RSL. These questions guide the search for primary studies and the extraction and synthesis of information needed to address them Revelo Sanchez, et al. [6]. This RSL includes two research questions, which are mentioned below.

RQ1: What are the current neural network-based vehicle license plate recognition technologies?

RQ2: What image pre-processing methods have been created specifically to enhance the performance of neural networks in vehicle license plate identification, and how do they influence the system's accuracy?

2.2. Search

This activity aims to select genuinely relevant studies that contribute to answering the research questions [8]. The suggested search plan involves a general search in specialized databases. Search words and synonyms were used to cover various documents for analysis.

Table 1 presents the terms, their synonyms, and the corresponding filters. The search was carried out in the databases indicated in Table 2, using fields such as title, keywords, abstract, and full text. Table 3 shows the results of the search strings for each term, including its synonyms and the relevant filters.

Table 1.
Term, synonyms, and filters to structure the search string.

Term	Synonyms	Additional filters
Vehicle license plate recognition with neural network	Vehicle license plate recognition with deep learning	Hybrid, Convolutional, transformers, for parking
	Vehicle license plate recognition with artificial intelligence	
	Vehicle license plate recognition with automatic learning	

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Table 2.
Main term and databases.

Term	Database
Vehicle license plate recognition with neural network	IEEE Xplore, Science Direct, DOAJ, Scopus

Table 3.
Search string.

Main term	Search string
Vehicle license plate recognition with neural network	("Vehicle license plate recognition with neural network" OR "Vehicle license plate recognition with artificial intelligence" OR "Vehicle license plate recognition with deep learning" OR "Vehicle license plate recognition with automatic learning") AND (hybrid OR convolutional OR transformers OR of parking) AND (publication year >= 2020).

2.3. Selection

All studies included in this review were examined, considering criteria such as title, keywords, and abstract, to identify those that address models and technologies related to vehicle license plate recognition. Likewise, inclusion and exclusion criteria were defined, as shown in Table 4.

Table 4.
Criteria.

Inclusion Criteria	Exclusion Criteria
Time (2020 - 2024). Studies that refer to technologies applied to vehicle license plate recognition. Title of the document related to technologies or automatic recognition of vehicle license plates.	Research in languages other than English and Spanish will not be considered. Duplicate items. Literature reviews and studies that do not have the respective bibliographic citation are not considered.

The systematic literature review (SLR) process, depicted in Figure 2, follows a structured methodology to identify, filter, and analyze relevant research articles on vehicle license plate recognition. The process begins with a search string applied across four major academic databases: Scopus, IEEE Xplore, ScienceDirect, and DOAJ. Initially, a broad set of studies is retrieved, and a duplicate removal step is conducted to eliminate redundant entries. The pre-selection phase then applies filtering criteria based on titles, keywords, and abstracts, while also excluding review articles to ensure only primary research is considered. Following this, a more detailed selection phase is performed, where full-text reading and quality assessment criteria are applied to determine the final set of studies for inclusion. This structured approach ensures a rigorous and unbiased review of the most relevant literature, improving the reliability and comprehensiveness of the findings.

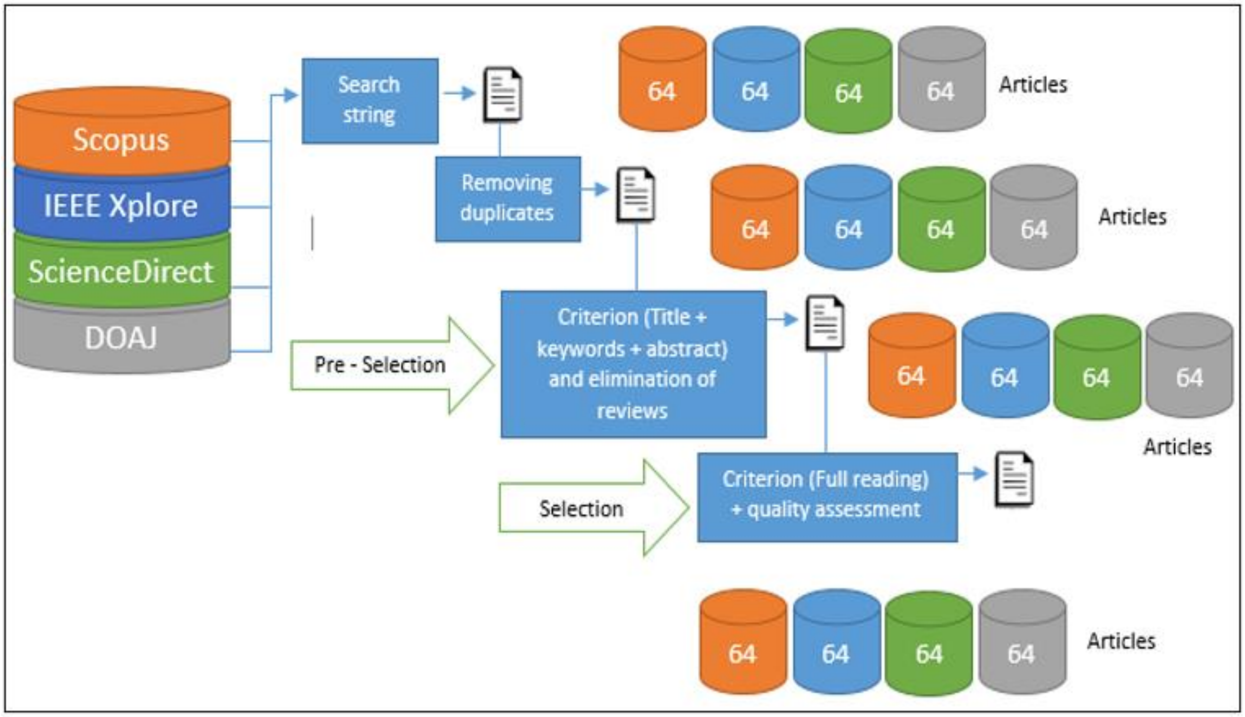

Figure 2.
Results of study sources, adapted from.
Source: Barón, et al. [9]

2.4. Quality Assessment

The selected documents are evaluated using four criteria to ensure their quality: relevance of the content to address the key questions of the review, clarity of the research objectives, a detailed description of the context of the study, and clear presentation of the results. These criteria address three essential aspects: the minimum quality level, credibility, and relevance [7]. After carefully examining the 80 complete documents, 66 were selected that met the criteria established as essential sources for the systematic review. These documents are presented in Table 5 and their bibliographical references, ordered chronologically by year of publication.

2.5. Data Extraction and Synthesis

The main objective of this systematic study is to evaluate the current state of license plate recognition. After searching for terms in each database and applying the two corresponding phases, the results obtained in the relevant files and the appropriate citations from their authors are presented below.

Table 5.
Studies included in systematic review

Year	Amount	Reference
2020	22	Salazar Mayorga [10] ;Zhang, et al. [11] ; Tourani, et al. [12] ;Zou, et al. [13] ;Cai, et al. [14] ;Liu, et al. [15]; Rusakov [16] ;Pustokhina, et al. [17] ;Shrivastava, et al. [18];Darapaneni, et al. [19] ; Sarif, et al. [20]; Henry, et al. [21]; Mai, et al. [22]; Gong, et al. [23]; Liu, et al. [24]; Riaz, et al. [25]; Slimani, et al. [26]; Jamtsho, et al. [27] ;Acosta and Toruño [28];Espinoza Lopez and Portocarrero López [29] and Subhadhira, et al. [30]
2021	12	Suárez Mosquera, et al. [31]; Xu, et al. [32]; Kong, et al. [33]; Huang, et al. [34]; Duan, et al. [35];Shashirangana, et al. [36]; Joshua, et al. [37]; Ali, et al. [38]; Julius Fusic, et al. [39]; Awaimri, et al. [40]; Gonzáles [41]; Shariff, et al. [42] and Cáceres [43]
2022	13	Ilayarajaa, et al. [44]; Kukreja, et al. [45]; Rashtehroudi, et al. [46]; Suvon, et al. [47]; Weihong and Jiaoyang [48]; He and Hao [49]; Samadzadeh, et al. [50]; De Oliveira, et al. [51]; Onim, et al. [52]; Alghyaline [53]; Valdeos, et al. [54]; Martínez-Prado, et al. [55] and Pérez Silva [56]
2023	17	Naji, et al. [57]; Amato, et al. [58]; Aqaileh and Alkhateeb [59]; Kundrotas, et al. [60]; Danilenko [61]; Zhao, et al. [62]; Tsai, et al. [63]; Medvedeva, et al. [64]; Liu and Zhu [65]; Saitov and Filchenkov [66]; Sugiyono, et al. [67]; Jawale, et al. [68]; Corrales Estrella and Sánchez Bocanegra [69]; Vargas, et al. [70] and Satti Babu, et al. [71]
2024	2	Ramajo-Ballester, et al. [72] and Neupane, et al. [73]

A detailed analysis of various vehicle license plate recognition technologies was carried out.

In the research carried out by Salazar Mayorga [10] 34 videos were collected, of which 2,419 photographs were obtained with a resolution of 3,240 x 2,148 pixels. After choosing the most pertinent ones, a database with 10,299 images was generated, suitable for training, validation, and evaluation of the model. In the training, a convolutional neural network was used to categorize the occupancy of parking spaces, achieving an accuracy that exceeded 90% in tests with unknown images. However, restrictions were detected in situations of occlusions. The findings, comparable to previous research, corroborated the model's effectiveness, highlighting the impact of the camera's location and the environmental conditions on its accuracy.

Scientists developed the ALPR system through the research mentioned in Tourani, et al. [12]. They use two independently trained and fine-tuned Yolo V3 networks to identify and recognize license plate characters. This method addresses common problems of optical character recognition (OCR) by treating character identification as a classification problem. In addition, several strategies were implemented to extend the training dataset. The experimental results demonstrate the accuracy and effectiveness of the system in real-world situations.

The study mentioned in Cai, et al. [14] presents a novel algorithm for recognizing vehicle license plates in the United States. This approach combines several deep learning models. The process is divided into two main steps: first, the license plate and the state to which it belongs are identified, and then the characters are recognized. An optimized version of YOLO v3 is used for detection, while character recognition is performed with CRNN, and state classification is done with ResNet-50. The results demonstrate high accuracy in both tasks, which supports the effectiveness of the proposed model.

The study mentioned in Rusakov [16] proposes a modular approach based on convolutional neural networks (CNN) to improve the speed and accuracy in license plate recognition. A Single Shot Detector (SSD) model detects license plates, which can accurately identify and locate the license plate within an image. Subsequently, a ResNet convolutional neural network is responsible for quickly recognizing and locating each character on the plate. The experimental results indicate that this modular strategy significantly improves the system's performance and speed while maintaining high accuracy levels compared to traditional methods.

The study mentioned in Shrivastava, et al. [18] analyzes current technologies for non-polychromatic vehicle license plate recognition (VRNPR) and highlights the advantages of convolutional neural network (CNN)- based approaches over traditional methods. It proposes a five-step model for VRNPR that includes vehicle image capture, preprocessing, license plate localization, character segmentation, and subsequent recognition. The researchers conclude that the application of CNN significantly improves accuracy and processing speed compared to previous models, making it a fundamental tool for current traffic safety and regulation.

The study in Darapaneni, et al. [19] describes a vehicle parking management system (VPMS) based on computer vision. This system aims to improve the management and control of parking spaces, especially in areas with high congestion. Due to the increase in the number of cars, optimizing the use of these spaces has become a significant challenge. The proposed solution is based on real-time license plate detection and recognition from video sequences, using the YOLOv3 algorithm and OpenCV to achieve high accuracy.

The study in Sarif, et al. [20] presents a license plate recognition (LPR) system based on deep learning techniques designed for vehicles in Bangladesh. This system consists of three stages: first, it uses YOLOv3 to detect license plates; then, it applies a segmentation method adapted to the characteristics of license plates in the country; finally, it employs a convolutional neural network (CNN) to recognize characters. Using a dataset of 2000 images reflecting various environmental conditions, the system achieved an accuracy of 97.5%.

The study mentioned in Gong, et al. [23] analyzes the recognition of Chinese vehicle license plates in complex environments, focusing on the challenges caused by the tilt and distortion of the captured images. To address these issues, an optimized convolutional recurrent neural network (CRNN) model is presented, which combines deep convolutional neural networks (DCNN), recurrent neural networks (RNN), spatial transformer networks (STN), and connectionist temporal classification (CTC). This combination of techniques enables end-to-end recognition without explicitly segmenting characters, thereby increasing accuracy and significantly reducing segmentation errors.

The study referenced in Riaz, et al. [25] evaluates an automatic license plate recognition (ALPR) system that uses YOLOv3 for detection and CRNN for classification to improve vehicle identification. The researchers used the AOLP dataset and segmented the images into three categories: 40% for training, 20% for validation, and 40% for testing. The results reflected an overall recognition rate of 86%, with an accuracy of 88% for three-letter license plates and 99% for four-letter license plates. Furthermore, the recognition rate increased to 96% by integrating temporal redundancy.

The research cited in Kong, et al. [33] deals with the application of federated learning in vehicle license plate recognition (FedLPR), using the ability of mobile devices to train the model and ensure user privacy efficiently. In this study, the progress of a model optimized for mobile devices is presented, which includes a license plate detection (LPD) and recognition (LPR) system, which consists of a tilt correction algorithm, to increase the registration accuracy. The experiments show the model's effectiveness in terms of accuracy and speed, even in challenging real-world contexts. In addition, a mobile application is launched to assess its performance more thoroughly.

The report in Duan, et al. [35] analyzes the Vehicle License Plate Identification (LPR) technology, essential in Intelligent Transportation Systems. This method facilitates the identification of license plates through vehicle identification and character study in surveillance images or videos. They examine the challenges that affect the system's accuracy, such as the images' low quality and design. To address these issues, they suggest a practical solution based on the Single Shot MultiBox detector to identify license plates and a convolutional neural network for character interpretation. Likewise, the Deep

Rebirth method reduces the model, improving its computing performance and simplifying real-time processing.

The research cited in Joshua, et al. [37] examines an automated license plate recognition system to improve efficiency in Indonesian parking lots. Typically, parking staff manually perform license plate registration, which can be laborious and error-prone. To solve this problem, they suggest applying the YOLO (You Only Look Once (YOLO) model for image license plate identification and a ResNet neural network for categorizing the numeric characters of such license plates.

In the research mentioned in Julius Fusic, et al. [39] convolutional neural networks, specifically the AlexNet model, recognize characters and segment vehicle license plates. The transfer learning method increased the model's accuracy using previously labeled images. An optical character recognition (OCR) system trained with a specific set of characters also facilitates highly accurate text extraction. The findings showed a notable increase in license plate recognition and identification accuracy.

The study Awaimri, et al. [40] provides a methodical review of Automatic Number Plate Identification (ANPR) systems. The study includes several techniques and algorithms to identify and recognize number plates in images recorded by cameras and used in traffic management, vehicle protection, and parking regulation. The ANPR procedure includes four key stages: Image collection and pre-processing, Number plate identification, Character segmentation, and Character identification. The recognition rates of the algorithms evaluated in the study vary between 82% and 99%, demonstrating their effectiveness in different contexts and capture conditions.

The research in Rashtehroudi, et al. [46] suggests an automatic license plate recognition (ALPR), focusing on Iranian license plates. This objective combines segmentation and optical character recognition (OCR) in a unified process based on deep learning methods, particularly the YOLO model. The study highlights the importance of image pre-processing to increase their quality and the relevance of procedures to obtain character features. These include conventional statistical evaluations and sophisticated methods based on convolutional neural networks. The findings indicate an accuracy of 99.2% in character identification, representing a considerable advance in previous research.

The research mentioned in Onim, et al. [52] showcases BLPnet, a deep neural network (DNN) specially built for the Automatic License Plate Recognition (ALPR) of Bengal vehicles. Its structure consists of three stages: The first one uses an adapted version of NASNet Mobile, to identify the vehicle region effectively; The second, a customized model based on InceptionV3, facilitates accurate license plate identification; and the third, an innovative Bengali OCR engine, can process artifacts, such as motion blur. Compared to baseline models such as YOLO and Tesseract, BLPnet achieves a 5% increase in detection accuracy and a 20% decrease in processing time.

The research in Valdeos, et al. [54] shows a system for accurately identifying and recognizing vehicle license plates based on convolutional neural networks trained explicitly with YOLOv4. Python and OpenCV are used for image processing. The newly employed database incorporates vehicle registrations from Peru, which improves the system's performance and enables 100% accuracy without false positives. The study's findings highlight that this method provides faster and more reliable processing than previous models, particularly those created in Europe, with significant implications for future vehicle management.

The research in Amato, et al. [58] offers a detection approach based on convolutional neural networks (CNN), designed to work efficiently even under fluctuating environmental circumstances. Its ability to generalize is demonstrated when evaluated with images taken from viewpoints different from those used during training. In addition, it includes a comparative study with existing techniques, showing that its CNN-based approach matches or exceeds conventional methods in terms of accuracy and effectiveness.

The research mentioned in Kundrotas, et al. [60] employs a modified Hourglass neural network based on the CenterNet framework for object detection. This alteration decreases the network size by 40%, resulting in highly effective performance with an accuracy of 96.19% and a processing speed of 2.71 ms (or 405 FPS). The algorithm is verified through publicly accessible data sets, which shows remarkable advances in the speed and effectiveness of license plate recognition systems, particularly in challenging contexts.

In the research mentioned in Tsai, et al. [63] the writers suggest a three-phase license plate identification procedure: localization, character segmentation, and recognition. To increase the accuracy, they implement a convolutional neural network. The identification is efficiently carried out through OpenCV, which facilitates the localization of license plates with high accuracy in different circumstances, including those with blue and yellow hues. By improving the network parameters and implementing error back-propagation methods, the system achieves an accuracy rate exceeding 97%.

The research in [66] shows a deep convolutional YOLOv8 neural network for license plate identification, achieving a mean accuracy (mAP@50) of 0.983. These findings demonstrate significant speed and accuracy compared to existing systems. The study uses the TrOCR transformer model for optical character recognition, which increases the accuracy in identifying license plates from nations such as Armenia, Kazakhstan, Ukraine, and Moldova. Furthermore, the research highlights the challenges in license plate identification, including variability in design and environmental conditions such as light and noise.

In the study cited in Jawale, et al. [68] on character recognition, four models were analyzed and compared: CNN, MobileNet, Inception V3, and ResNet50. CNN performed the best, achieving an accuracy of 98.5% and a loss of 4.25%. The authors conclude that the proposed ALPDR system, especially with the convolutional neural network model, is highly effective under various conditions, such as low illumination, blur, and tilt.

3. Discussion

This section answers the research questions posed above.

RQ1: The current state of neural network-based technologies for license plate recognition is highly advanced and constantly evolving. Neural networks, especially convolutional neural networks (CNNs), have emerged as the primary tool to address challenges in license plate recognition due to their ability to learn and extract relevant features from images.

3.1. Techniques Used:

- CNNs are highly effective for image processing. They can identify patterns and features at different scales and levels of complexity. CNNs are particularly useful for recognizing alphanumeric characters on license plates.
- Recently, models such as YOLO (You Only Look Once) and variants of it, such as YOLOv3, YOLOv4, and YOLOv8, have also been used. These models allow real-time detection, which is essential for applications such as traffic control and public safety.

3.2. Technical Challenges:

- Despite advances, significant challenges remain, such as variability in license plate design, different lighting conditions, or occlusions. These factors can affect the accuracy of the recognition system.
- Image quality also plays a crucial role; blurry or low-resolution images make it difficult to identify characters correctly.

3.3. The Future

- Research continues to improve deep learning models, image preprocessing algorithms, and transfer learning approaches to develop more robust and accurate systems.

RQ2: Pre-processing methods are essential to improve the quality of images before they are fed into neural networks, increasing the accuracy of license plate recognition.

3.4. Common Pre-Processing Techniques

- Contrast and Brightness Adjustment: These techniques improve the visibility of characters in different lighting conditions.
- Normalization: Ensures images are consistent in size and format, making it easier to train the neural network.
- Noise Removal: Filters and techniques such as mathematical morphology are applied to remove background noise that could confuse the system.
- Image Segmentation involves locating and extracting the region of interest (the license plate) from the entire image, removing unwanted elements, and focusing solely on the license plate.

3.5. Impact on Accuracy

- Implementing these pre-processing techniques can significantly increase the correct recognition rate. For example, adjusting the contrast can make the characters on a license plate more contrasting against the background, making the model's task more manageable.
- Segmentation techniques also allow neural networks to focus on the relevant part of the image, improving recognition accuracy and efficiency.

3.6. Integration with Deep Learning Models

- Some modern approaches integrate preprocessing directly into the deep learning model pipeline, using neural networks to perform fine-tuning and segmentation automatically. This can result in a more efficient system with lower computational overhead.

4. Conclusions

Neural networks, especially convolutional neural networks (CNN), are identified as crucial tools in license plate recognition. Their ability to learn and extract meaningful features from images significantly improves the accuracy and speed of the process.

Implementing these systems automates recognition and increases efficiency in critical applications such as traffic control and public safety.

Despite progress, technical challenges affecting recognition effectiveness include variability in license plate designs, adverse lighting conditions, and occlusions. These difficulties can negatively impact the overall accuracy of recognition systems.

Recognition success depends heavily on image preprocessing methods. Techniques such as contrast adjustment, normalization, and segmentation are critical to improving the quality of images before they are analyzed by neural networks, which can considerably increase recognition rates.

The evolution of deep learning algorithms and the development of methodological benchmarks provide a viable framework for future research. This includes moving towards more robust models that integrate pre-processing techniques directly into the deep learning workflow.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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