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Power of User Perception on Pedestrian Quality of Service

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Abstract

Research progress has been made in recent years in developing service or performance indicators (SPI) or methods to better measure or evaluate service or quality for pedestrians in a local context. The majority of SPIs relate objective (measurable) characteristics or attributes of the right-of-way, with the user's perceived output variable (e.g., perceived comfort). Traditionally, these methods do not consider the user's perspective of the input variables. However, there is evidence that the direct contact of pedestrians with the environment justifies an exploration of the contribution of perceptions to that end. This study explores the power of user perception onsite to explain the sidewalk quality of service (QoS), compared to physical and other measurable traditional inputs. Information of physical characteristics, traffic, and perceptions were acquired in 30 different urban rights of way in Bogota, Colombia. By comparing the explanatory power and the goodness of fit of different scenario models, perceptions have been found to be an important predictor to pedestrian perception of QoS. In the light of the results, this paper provides a generalized conceptual framework to explain QoS that complements the existing one and discusses the implication of the use of QoS as the outcome variable.

Research progress has been made in recent years in developing indicators or methods to better measure or evaluate service, quality, or performance of pedestrian infrastructure. A number of pedestrian service or performance indicators (SPIs) such as Walkability, WalkScore, level of service (LOS), and others, have been developed and reported in the literature. In general, these methods relate physical characteristics of the built environment (infrastructure geometry) and measurable disturbances (traffic or operational factors) with the perceived level in the SPI.

In transportation planning, the most traditional pedestrian SPI is the well-known pedestrian LOS (PLOS). At first, PLOS was based on pedestrian density and motorized traffic interactions (*1–3*). Performance was defined as the degree of saturation, in such a way that increasing overcrowding of the facilities represents an increase in perceived discomfort. However, its applicability is severely limited, as pedestrian infrastructure is seldom overcrowded (*4*). These methods have been evolving since the initial version in the 1970s. The most recent PLOS version reflects a multimodal approach, where other objective-measure variables of geometry, context, and operational factors are considered (*5*, *6*). Besides PLOS, transportation planners have limited methodologies that they can use. In addition, other measures to assess quality of service (QoS) are not standardized, or routinely utilized (*4*).

In other disciplines and in selected transportation industries (e.g., airports or transit), defining the level of satisfaction of a service considers the user's perspective. This provides us with a better understanding of the variables that affect the satisfaction. Conversely, pedestrian infrastructure SPIs have been mostly influenced by methods explaining the perceived performance or service by means of objective, measurable variables (e.g., geometry, operational factors).

The overarching objective of this paper is to explore the potential of user-oriented approaches to explain the QoS for pedestrians, by means of user perceptions, in contrast with traditional supply-oriented ones. Specifically, this paper assesses the strength of user perceptions in explaining QoS in comparison with

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traditional supply-oriented methods, based on objective measures. Purposely, the concentration is on the comparative analysis of three groups of variables (geometry, operational factors, and perceptions), rather than the interpretation of single variables. Based on environmental psychology theories, it is hypothesized that sensory input from the environment plays a role in the final user's satisfaction, and, thus, in the way they behave. The aim is to provide evidence to enrich the general framework to explain pedestrian SPIs.

Literature Review

Traditionally, pedestrian SPIs have used a variety of different user-perceived variables as response or explained variables, or "proxy" to the indicator. The most common variables selected in the literature are satisfaction, comfort, and stress (*3, 7–17*). Specifically for PLOS, comfort as a proxy also started to be used in the late 1980s (*13*). However, it was after the start of the new century when the term "comfort" began to be used more commonly (*9, 11, 15, 17–19*). Satisfaction was considered for pedestrians only after 2005 and is still used to understand the service provided by pedestrian infrastructure (*7–12*).

Initially, PLOS resembled the motorized traffic LOS methodology, based on the flow–capacity relation (*20*). This approach considers the changes that the flow–capacity relation produces on the QoS that an infrastructure is rendering to its users as a predictor variable (*1*, *2*, *21*, *22*). LOS methods have evolved over time. The recent multimodal approach for urban traffic facilities brought geometric variables, beyond operational service measures, as in the past. Particularly for pedestrians, a variety of geometric variables are included (*6*, *20*).

To estimate the main SPI, the common practice is to use measurable onsite attributes, both geometric and operational factors, as explanatory variables. By means of linear regression, probabilistic or any other models, the proxy to the indicator is explained by means of a series of measurable predictors. Geometric attributes include, for example pedestrian infrastructure width or buffer width, and operation related attributes such as vehicular flow, speed limit, and vehicle conflicts (*5–7, 9, 11, 12, 14, 19, 21, 23–42*). User perceptions are not commonly used as independent variables.

Unlike motorists, pedestrians have direct contact with the environment. Pedestrians are exposed to the environmental stimuli that manifest through visuals, smells, and noises. In addition, people use sidewalks (infrastructure) for other activities beyond the functional movement, and they frequently move in groups, while interacting with the environment (*44*). Environmental psychology states that the first step in the processing of environmental stimuli is through the senses and the results are perceived in sensations and emotions (*45*). This process concludes in behavioral "approach or avoidance" responses, according to the Merhabian-Russell model developed in 1972 (*45*, *46*). Thus, environmental stimuli influence the decision of using certain infrastructure or avoiding it entirely. However in the past, it was found that there is low correlation between the SPI perceived by users and that which is estimated by using measurable attributes in-situ (*47*, *48*). In an attempt to fill this gap, Fernández-Heredia et al. suggested that including user perceptions to mode choice models could improve their performance (*49*). Furthermore, Vallejo-Borda et al. proposed a model that contemplates these environmental stimuli to forecast the pedestrian QoS (*50*). However, it is not common to find models that include perceptions to estimate QoS in the literature.

Methods

To explore the power of pedestrian perceptions on QoS, random intercept surveys were conducted and in-situ objective information (traffic counts and infrastructure audit) was acquired. The questionnaire contained perception and socio-demographic questions and was administrated at the same time as the counts and audit were performed at the specific location. The general process comprised: (1) identifying different pedestrian SPIs in the literature, their proxies, and different explanatory variables; (2) planning and performing the data acquisition in different rights-of-way where geometry, operational factors, and perceptions were measured; (3) developing different ordinary least squares (OLS) models for QoS with different combinations of groups' variables; (4) comparing and analyze OLS models; and (5) discussing results.

The survey questionnaire began with a question about perceived QoS in a specific sidewalk ("infrastructure service") in a 0 to 10 Likert scale ("0" being poor and "10" being excellent). Then, respondents were asked to rate a set of questions and statements about attributes of the location and perceptions of intangible states, conditions, or emotions in the same Likert scale. Manual traffic counts of cars, buses, trucks, motorcycles, bicycles, and pedestrian were conducted. The list of variables in the questionnaire is shown in Table 1.

The intercept survey was applied in 30 locations in different districts in Bogota, Colombia, reaching a total of 1,056 valid responses (see Figure 1). The survey locations selected included a great variety of geometry dimensions, traffic flows (motorized, bicycles, and pedestrian), and presence of relevant attributes (e.g., arborization). Surveys were carried out between June 2 and June 19, 2018, during the daytime on working days. Each survey lasted around 8 minutes approximately and the overall

Table 1. Description of Variables Associated with User Perception, Operational, and Geometric Factors Measured Onsite

		Variable	Description	Range
Perception	1.1	Infrastructure service	Rate the service provided by this infrastructure	0 to 10
	1.2	Peddlers' presence	When walking in this infrastructure, the peddlers bother me	0 to 10
	1.3	Pavement	Rate the pavement in this infrastructure	0 to 10
	1.4	Road signs	Rate the road signs in this infrastructure	0 to 10
	1.5	Street lights	Rate the street lights in this infrastructure	0 to 10
	1.6	Traffic pollution	When walking in this infrastructure, the traffic pollution bothers me	0 to 10
	1.7	Street trees	I like the arborization in this infrastructure	0 to 10
	1.8	Street attractiveness	Generally, I use this street and avoid parallel streets	0 to 10
	1.9	Traffic noise pollution	When walking in this infrastructure, the noise bothers me	0 to 10
	1.10	Presence of other pedestrians	When walking in this infrastructure, the presence of other pedestrians bothers me	0 to 10
	1.11	Avoids sidewalk	When using this street, I'd rather not walk on this sidewalk	0 to 10
	1.12	Pleasure	It is pleasant when walking in this infrastructure	0 to 10
	1.13	Street safety	I feel safe, regarding accidents, when using this infrastructure	0 to 10
	1.14	Overcrowded pedestrian infrastructure	The crowd of pedestrians prevents me from using the infrastructure	0 to 10
	1.15	Conflicts with bicyclists' traffic	The bicyclists' traffic bothers me	0 to 10
	1.16	Personal safety	I feel safe, regarding crime safety, when using this infrastructure	0 to 10
Operational factors	2.1	Bicycles using the vehicle lane	Count during 5 min in the infrastructure	Number
	2.2	Motorcycles	Count during 5 min in the infrastructure	Number
	2.3	Lightweight vehicles (cars)	Count during 5 min in the infrastructure	Number
	2.4	Buses	Count during 5 min in the infrastructure	Number
	2.5	Heavyweight vehicles (trucks)	Count during 5 min in the infrastructure	Number
	2.6	Pedestrians	Count during 5 min in the infrastructure	Number
	2.7	Bicycles using the bike lane	Count during 5 min in the infrastructure	Number
	2.8	Others using the sidewalk	Count during 5 min in the infrastructure	Number
	2.9	Car speed	Average speed of vehicles	(km/h)
	2.10	Number of parked vehicles	Count in the infrastructure	Number
	2.11	Speed limit	Speed limit in the street	(km/h)
	2.12	Length of driveways	How much of the sidewalk length is used by driveways	(m)
	2.13	Number of pedestrian entrances	Count in the infrastructure	Number
	2.14	Number of driveways	Count in the infrastructure	Number
	2.15	Number of conflicts	Count in the infrastructure	Number
Geometric factors	3.1	Sidewalk width	Measurement of the street feature/perception on the width	m / 1 to 10
	3.2	Distance between intersections	Sidewalk length without being interrupted	(m)
	3.3	Number of trees	Count in the infrastructure	Number
	3.4	Number of lanes	Count in the infrastructure	Number
	3.5	Buffer?	Yes or No question	(Yes=1/No=0)
	3.6	Bus stop?	Yes or No question	(Yes=1/No=0)
	3.7	Road median?	Yes or No question	(Yes=1/No=0)
	3.8	Buffer width	Measurement of the street feature	(m)
	3.9	External lane width	Measurement of the street feature	(m)
	3.10	Lane width	Measurement of the street feature	(m)
	3.11	Street width	Measurement of the street feature/perception on the width	(m) / 1 to 10
	3.12	Shoulder width	Measurement of the street feature	(m)
	3.13	Bike lane width	Measurement of the street feature	(m)
	3.14	Roof length	How much of the nearby structure's roof is over the public space	(m)
	3.15	Number of ramps	Count in the infrastructure	Number
	3.16	Continuous?	Yes or No question—Is the sidewalk uninterrupted?	(Yes=1/No=0)
	3.17	Separate facade?	Yes or No question	(Yes=1/No=0)
	3.18	Separation of facades	Measurement of the street feature—separation from the sidewalk	(m)

Table 2. Proposed Scenario Models

	Model 1 (M1)	Model 2 (M2)	Model 3 (M3)	Model 4 (M4)	Model 5 (M5)	Model 6 (M6)	Model 7 (M7)
Geometric factors	X				X	X	X
Operational factors		X		X	X		X
Perceptional factors			X	X		X	X

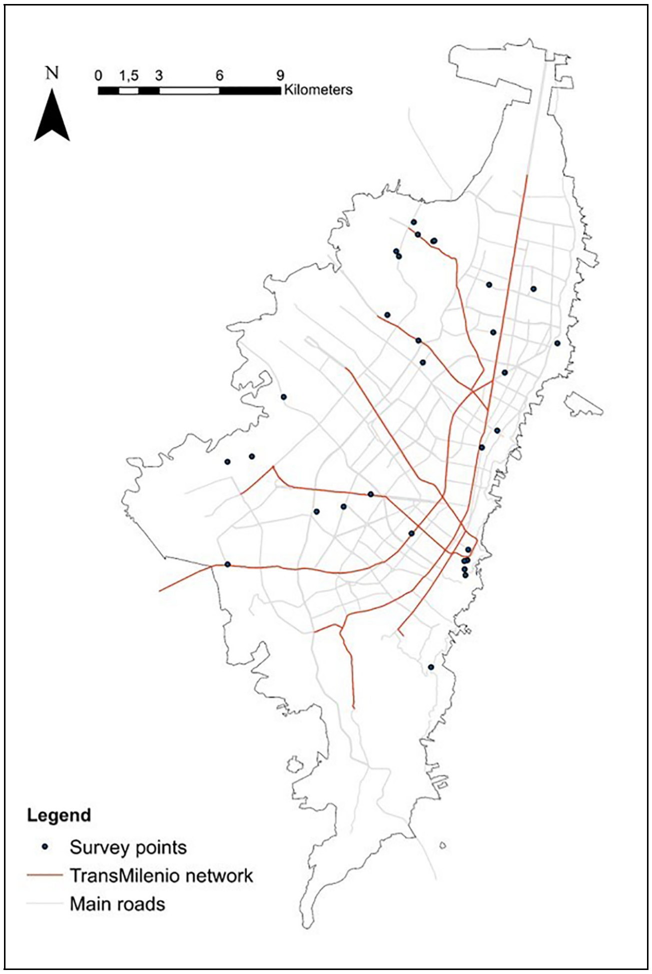

Figure 1. Audited sidewalks locations.

response rate was 33.2%. Surveyors picked respondents at random (one in every three passing pedestrians) to avoid self-selection bias. In addition, randomness assures variety in the sample. However, other mistakes, such as response bias, where some respondents did not take the survey seriously, were not considered.

Once the survey was performed, several OLS models were developed, systematically combining three groups of variables: geometric (G -variables), operation (O -variables), and perceptional (P -variables) information. Table 2 presents the models with different combinations.

The OLS model (Equation 1) uses an equation rather than a probability model. Thus, the regression will show the estimates for each explanatory variable in a relation that can be presented as:

$$Y_i = \beta_0 + \sum_1^g \sum_1^{k_g} \beta_{k_g} x_{i,k_g} + \varepsilon \tag{1}$$

where Y: Dependent variable (QoS)
β_0: Intercept
g: Group of variables
k_g: Number of variables in a given group g
β: Vector of estimable parameters x
x: Vector of independent variables
ε: Error term
i: Number of observations.

We abstain from providing a detailed interpretation of the variables in the models, but rather provide an overall and comparative approach of the proportion of the variance in the dependent variable that is predictable from different groups of independent variables. As such, the contribution of each group of variables can be assessed independently and combined with other groups. The coefficient of determination (R-squared) of each model is used as an indicator of the power each group of variables in explaining the perceived QoS and the F-test of lack-of-fit. The R-squared is defined as the ratio between the explained variation and the total variation, and can be calculated using Equation 2 (*51*).

$$R^2 = \frac{\sum_{i=1}^{n}\left(\widehat{Y}_i - \bar{Y}\right)^2}{\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2} \tag{2}$$

where Y_i represents the perceived QoS, $\widehat{Y}_i$ is the estimated QoS with the model, and $\bar{Y}$ is the average QoS. To identify the contribution of a variable x_j of the variation of a dependent variable y the partial R-squared can be used (*52*). The partial R-squared can be computed using Equation 3.

$$R^2 = \sum_{j=1}^{p-1} a_j r_{jp} \tag{3}$$

where a_j is the standardized regression coefficient of the j^{th} explanatory variable, p^{th} is the dependent variable, and r_{jp} is the Pearson correlation between j and p (*52*).

For the corresponding multiple regression model (with response Y_i), it is wished to know what percentage of the variation which is not explained by a given predictor variable is explained by the others. In multiple regression models, unlike simple linear regression, the regression sum of squares (SSR) can be decomposed in a variety of ways, depending on the order in which variables are added (*53*).

Results and Analysis

According to the results, perceptions represent a dominant role in explaining the variance in the perceived QoS for pedestrians, which is predictable from the entire set of explanatory variables. Models 1 to 3 allowed the examination of the individual effect of each of the three groups of variables to explain QoS. When considering groups independently, the model considering perceptional variables (P -variables) (M3) explains almost the variance of the dependent variable 3.5 times more than models with only geometric (G -variables) or operational variables (O -variables) (i.e., M1 and M2). It was found that the R-squared of O -variables is 0.153 and the R-squared of G -variables reaches only 0.164, while the one for M3 is 0.534. Table 3 shows the results.

For M4 to M7, which combine more than one group of variables, the coefficient of determination was disaggregated into coefficient of partial determination (partial R-squared) and the pure effect was isolated to observe the participation of different groups of variables into the overall R-squared. The model where perceptions are absent (M5) has even lower R-squared than models that consider them. The model including all three groups of variables (M7) reaches the highest coefficient of determination (R^2 = 0.561). However, the difference in the coefficient of determination between M7 and the simplified model with only P -variables (M3) is 0.027. In addition, the contribution of G -variables and I -variables in explaining QoS (M5 and M7) is similar.

When analyzing the contribution of each group of variables in each of the models (Table 3), it was possible to quantify the relative importance of each group of predictors (pure contribution) and the joint contribution (via commonality analysis). The contribution of perception (P) variables account for at least 62.7%, while operational variables (O) and geometric variables (G), at most, account for 23.4% and 29.0% respectively, in the absence of perceptional variables (M5). Notice that commonality is higher in the models without perceptional variables. The minor pure contribution of G -variables and O -variables in M7, compared with P -variables and the commonalities, is noteworthy.

The coefficient of determination (R^2) automatically increases when extra explanatory variables are added to the model (*51*). The adjusted coefficient of determination (Adj- R^2) controls for the degrees of freedom and adjusts the coefficient of determination accordingly, to make a fair comparison that is not dependent on the number of variables. Notice that, after this correction, the model including all groups of variables (M7) is the second best (Adj- R^2 = 0.534), after M6. Using the F-value of the regression (also known as F test for lack-of-fit), it was analyzed whether a given model fits the data better than the intercept-only model. In this case, M5 shows the test's lower level of significance, but it is still higher than the standard significance levels ($\alpha = 0,01$). The model showing the best fit is the one including only P -variables (M3), which is the fourth best considering both the R^2 and Adj- R^2.

Table 3. Disaggregated Contribution of Groups of Factors to the Overall R-squared for Different Models

Model	k	G (pure)	O (pure)	P (pure)	Comm.	R-sq.	Adj-R-sq.	F-test
M1	18	0.164 (100.0%)	na	na	na	0.164 (100.0%)	0.150	11.310
M2	23	na	0.153 (100.0%)	na	na	0.153 (100.0%)	0.134	8.102
M3	18	na	na	0.534 (100.0%)	na	0.534 (100.0%)	0.525	64.170
M4	41	na	0.016 (2.9%)	0.397 (72.2%)	0.137 (24.9%)	0.550 (100.0%)	0.531	29.370
M5	41	0.062 (29.0%)	0.050 (23.4%)	na	0.103 (47.7%)	0.215 (100.0%)	0.183	6.756
M6	36	0.019 (3.4%)	na	0.386 (69.8%)	0.148 (26.8%)	0.553 (100.0%)	0.536	33.980
M7	59	0.010 (1.8%)	0.008 (1.4%)	0.346 (61.7%)	0.197 (35.1%)	0.561 (100.0%)	0.534	20.910

Note: Comm = commonalities or redundancy; G = geometric; k = number of variables in a given group g; na = not applicable; O = operational; P = perceptional.

Discussion

The overall QoS perceived by pedestrians in a given location is related to the specific perceptions of physical characteristics and the surroundings, and the emotions produced in a given location. The greater explanatory capability of the QoS from *P* -variables acknowledges the influence of the environment on the overall individual quality assessment of a given sidewalk. The latter brings to light interesting topics to be discussed. Why would it be important to better understand walkers? What are the implications of considering perceptions in SPI methodologies? What are the limitations and issues associated with this topic?

The literature review provides the theoretical background to explain the results, based on environmental psychology. Perceptions identify, organize, and interpret sensory information, which is usually passive, but that also depends on recipients' expectations or memory. Previously, the effect of users' perceptions shown in the results of this study matches with those found for discrete choice models where Fernández-Heredia et al. presented an improvement on the choice models' performance by considering perceptions (*49*). In addition, this statement can also be validated considering that when perception variables are not included, the models' performance in relation to variance explanation presents a substantial decrease.

Results also suggest the overshadowing effect of *P* -variables over *O* -variables and *G* -variables. In M5, *O* -variables and *G* -variables complement each other, explaining 0.214 of the variance of QoS. Each one delivers 23.4% and 29.0% of that value, respectively (Table 3). In the presence of *P* -variables (M7), the absolute contribution of *O* -variables and *G* -variables to the R-squared drops substantially. *P* -variables deliver a greater percentage, ranging between 61.7% and 72.2%. Analyzing the overshadowing effect with the adjusted coefficient of determination, the best model is M6, which dismisses *O* -variables, and the effect of only using *P* -variables is 20 times greater than that of using only *G* -variables.

Other service-oriented industries in transportation, such as transit, airports, airlines, or carriers, regularly perform service quality surveys to users to monitor their service delivery performance or quality and to analyze the sources that produce it. The relationship individuals establish between their expectations and the perception of the service outcome influences the overall satisfaction, which ultimately affects their post-purchase behavior (*54*). Depending on the industry, the purpose of making customers loyal or frequent is usually financial, contractual, or branding. Could this be applied to the pedestrian? In environmental psychology, rather than post-purchase behavior, individuals will decide whether to approach or avoid a given environment. For pedestrians, this avoid–approach dichotomous behavior is key in the sustainable mobility paradigm described by Banister where active modes are key (*55*). Creating approachable sidewalks increases the utility of walking as a mode of urban transportation, potentially pulling travelers from other modes of transportation. Approachable sidewalks may also affect route choice.

The activity of walking intrinsically implies interacting with the environment, which entails exposure to the surroundings. Pine and Gilmore in their work entitled "Welcome to the Experience Economy" distinguish between the "service" and the "experience" (*56*). They associate an experience with a set-up stage, where guests interact with the environment and other actors. This "experience" can satisfy or disappoint, ultimately affecting the users' behavior, which is the final outcome of the cognitive process (*45*). Cities are increasingly providing high-quality premium pedestrian zones, where even flowers and expensive pavement are present, which resemble a stage to receive pedestrian as "guests," not anymore as "users."

Providing wide, well-paved, buffered sidewalks is important in providing good operational (functional) service to walkers, but providing or improving some intangible factors can also contribute to increase QoS (see *P*-variables in Table 1). Further research to identify what specific P-variables influence pedestrian perception of QoS, and to what extent, would be required. Linear regression, discrete choice modeling, and structural equation models incorporating user perception in SPI can increase their explanatory power, while bringing richer information for design and evaluation of pedestrian infrastructure. The results of this research have to be interpreted according to its context, which involved sidewalks and not other pedestrian facility types such as crosswalks, overpasses, underpasses, stairways, or rural paths. As this paper explores the capacity of perceptions to explain QoS, further research could emphasize which elements can be influenced in relation to user behavior, as well as the QoS influence on route and mode choice.

Conclusion

In this paper, the potential of user perception has been explored, compared with measurable objectives, as a means to explain pedestrians' QoS on sidewalks. By means of coefficients of partial correlation, this research has shown the contribution of the users' perception variables to explain perceived QoS, in comparison with the traditional operational and geometric variables, such as widths and traffic. Besides physical conditions of infrastructure, traffic of other modes of transportation, and interactions and operational factors, other factors or attributes, which are not necessarily tangible, can modify users' experience and deliver a higher QoS. The "experience" delivery concept presented in the literature and discussion has been found to match the pedestrian situation on sidewalks and is in accordance with actions implemented in cities worldwide.

Pedestrian perceptions have great potential in future research and application. If the goal of sidewalk design would be less normative (attaining standards) and it shifts to creating approachable and attractive sidewalks, using walker perceptions to relate to QoS (or other target variables such as satisfaction or comfort) would be indispensable. In relation to developing QoS evaluation or forecasting models using perceptions, advanced techniques such as Multiple Indicators Multiple Causes (MIMIC) such as the one applied by Vallejo-Borda et al. can be the path to be followed (*50*). In both cases, this paper raises an interesting discussion on the general approach and philosophy of complete streets manuals.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: A. Rodriguez-Valencia; data collection: J. A. Vallejo-Borda; analysis and interpretation of results: A. Rodriguez-Valencia, G. A. Barrero, H. A. Ortiz-Ramirez, J. A. Vallejo-Borda; draft manuscript preparation: A. Rodriguez-Valencia. All authors reviewed the results and approved the final version of the manuscript.

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