OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

# Cognitive-Affective-Behavioral Imbalance in Skin Cancer Prevention: A Magic-Square-Inspired Mathematical Model Using HINTS 2005 Data

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## ABSTRACT

A magic-square-inspired mathematical model was developed in this study to examine cognitive-affective-behavioral imbalance in skin cancer prevention among adults in the U.S. using data from the 2005 Health Information National Trends Survey (HINTS). After normalizing nine variables representing cognitive beliefs, affective responses, and protective behaviors and arranging them in a 3x3 structure, a magic-square imbalance score (MSIS) was calculated from variation among row, column, and diagonal means in a way that higher values represented greater imbalance. A total of 1,279 adults were included in the complete-case sample. The weighted mean MSIS reported 17.4, while the mean protection index reported 63.6. There was a decline in protection across increasing imbalance groups from 71.8 in the low-MSIS group to 62.7 in the middle group and 56.2 in the high group. Greater sunscreen non-use, shade non-use, and tanning exposure were associated with higher imbalance. In the adjusted analyses, cognitive-affective discordance alone was not significantly associated with protection. However, lower protection was associated with greater psychological adversity. For demographic profiles, women, older adults, and college graduates indicated stronger protective behavior. These findings suggest that an original quantitative approach may be provided by a magic-square-inspired framework to identify imbalance among beliefs, emotions, and behaviors related to skin cancer prevention.

Keywords: *Skin cancer prevention; magic square; cognitive-affective-behavioral imbalance; HINTS; health behavior; mathematical modeling*

## INTRODUCTION

Due to many of the major risk factors related to ultraviolet (UV) radiation exposure and potentially modifiable behaviors, skin cancer is a major public health concern. Harmful UV exposure may be reduced by sun-protective behaviors, such as sunscreen use, seeking shade, wearing protective clothing, and avoiding indoor tanning. However, these behaviors tend not to be consistently practiced. According to population studies, sunburn, inadequate sun protection, and indoor tanning were reported to remain common. However, there were still various risky behaviors that may have occurred within the same individuals (Buller et al., 2011; Coups et al., 2008). These findings suggest that it takes much more than simply determining whether a person uses sunscreen when understanding skin cancer prevention. At the

same time, it is necessary to understand how people perceive cancer risk and emotionally respond to that risk and also whether they reflect such thoughts and emotions in their actual behavior.

Prior studies have identified that there existed an important gap between knowledge and preventive action. What early studies found was that there were relationships among knowledge, perceived risk, and sunscreen use, but also how safer behavior was not guaranteed by knowledge alone (Berwick et al., 1992; Mermelstein and Riesenberg, 1992). More recent research has similarly found that individuals may have an understanding of the dangers of UV radiation but still continued risky sun-exposure practices (Kirk and Greenfield, 2017). Therefore, the Health Belief Model was applied to skin cancer prevention when examining not the knowledge alone a combination of perceived susceptibility, perceived severity, barriers, benefits, and self-efficacy (Nahar et al., 2013). These findings support how it is important to examine skin cancer prevention as a multidimensional behavioral process.

When explaining preventive behavior, cognitive and emotional factors may be particularly important. For example, perceived risk may influence health decisions, but different measures of risk perception are not necessarily linked to behavior in the same way (Dillar et al., 2012). Sunscreen and sunbed-related intentions have also been associated with beliefs related to personal control and self-efficacy (Pertl et al., 2010). In addition, whether individuals translate prevention intentions into action may be translated by attitudes, social expectations, and confidence in performing protective behaviors (Heckman et al., 2011). Research conducted on young adults has also indicated that both perceived susceptibility and perceived control may exist together with continued sunburn and inconsistent protective behavior (Heckman et al., 2012).

Affective responses are also related to this relationship. Concerns about skin cancer may motivate protective action, but excessive or poorly integrated concerns may not produce corresponding behavior. Prior study has found that skin cancer worry played a significant role in the connection between perceived risk and sunscreen use (Kiviniemi and Ellis, 2014). More broadly, information use and behavioral intentions have been associated with cancer worry and risk perception, and this suggests that cognition and emotion may not operate independently but together (Chae, 2015). Therefore, it is possible for a person to perceive high risk and experience substantial worry while still infrequently using sunscreen. Such an imbalance can be described as cognitive-affective-behavioral imbalance.

A novel way to quantify this imbalance may be provided by a mathematical approach. For example, magic squares are numerical grids constructed to make defined rows, columns, and diagonals produce equal sums. According to previous mathematical research, structural properties, construction rules, and patterns of magic squares were examined (Swetz, 2001; Velez, 2020). How balance around a magic constant characterizes normal magic squares and how changes in numerical placement after that balance have been demonstrated. This study adapts the principle of balance in a magic square rather than uses it as a numerical puzzle, organizing cognitive, affective, and behavioral variables. Therefore, greater deviation among these dimensions may be mathematically represented as a larger imbalance score.

In this study, data from the 2005 Health Information National Trends Survey (HINTS), a national survey developed by the National Cancer Institute, were used to examine cancer-related knowledge, attitudes, beliefs, information behaviors, and health behaviors (Cantor et al. 2005). A magic-square-inspired model is used to assess whether relatively balanced or imbalanced behavioral profiles are formed by skin cancer risk perception, prevention beliefs, worry, fear, information-related responses, sunscreen use, shade-seeking, and tanning behavior. In addition, this approach also inspires an interdisciplinary connection among mathematics, skin cancer prevention, and cognitive-affective health behavior while applying not a direct measure of neural activity but a behavioral model. This study specifically seeks to answer the research question of how cognitive-affective-behavioral imbalance, measured using a magic-square-inspired mathematical model, is associated with skin cancer prevention behaviors among U.S. adults. This study hypothesizes that adults in the U.S. with higher cognitive-affective-behavioral imbalance scores will report less consistent behaviors in skin cancer prevention, especially with sunscreen use and shade-seeking.

## METHODS AND MATERIALS

### Dataset and Study Design

In this study, publicly available data from the 2005 Health Information National Trends Survey (HINTS 2005) administered by the National Cancer Institute were used. As a national cross-sectional survey designed to measure cancer-related knowledge, beliefs, risk perceptions, information-seeking behaviors, and health behaviors among adults in the U.S., HINTS 2005 contained a total of 5,586 respondents and 550 variables. Only a subset received questions specifically in regards of skin cancer as HINTS 2005 randomly assigned respondents to cancer-specific modules. In this study, only participants who had valid responses for all nine variables were included for generating the mathematical model. Responses coded as refused, “don’t know,” not ascertained, or structurally missing were excluded in the analysis. In addition, the sunscreen responses among participants indicating that they did not go outside on sunny days were also excluded due to unavailability of directly placing them on the sunscreen-frequency scale. After the responses screening procedures, a total of 1,279 adults were included in the final complete-case sample.

### Selection and Coding of Variables

There were a total of nine variables selected to represent three dimensions of skin cancer prevention, namely; cognitive, affective, and behavioral factors. For cognitive variables, perceived likelihood of developing skin cancer, belief for a possibility of slowing or disrupting skin cancer development, and belief of behavioral and lifestyle-related contribution to cancer were included. For affective and decision-related variables, a frequency of skin cancer worry, feeling overwhelmed by prevention recommendations, and reluctance to undergo skin cancer examination due to fear were included. For behavioral variables, indoor tanning, sunscreen use, and shade-seeking were included.

A common scale from 0 to 1 was applied to the transformation of each variable. Higher scores consistently indicated greater prevention vulnerability, psychological barriers, or risky behavior. For

instance, sunscreen use was coded from 0 for "always" to 1 for "never." For indoor tanning, 0 was assigned for "no tanning," and 1 was assigned for the "highest reported frequency."

**Magic-Square-Inspired Mathematical Model**

The structural principle of a 3x3 magic square was used to generate the mathematical framework. In a traditional magic square, a total of nine values are arranged to make the sums of each row, column, and diagonal equal to a common magic constant. In this study, these balance properties, the derivation of the magic constant, and construction of 3x3 and 4x4 normal magic squares were all used. In particular, this principle was adapted not to create a traditional magic square but to measure balance. These three rows were specified a priori to represent cognitive, affective, and behavioral domains. The three columns were organized as risk/threat, control/protection, and agency/avoidance so that each column contained one conceptually related variable from each domain. This arrangement was selected before analysis without being optimized to maximize statistical associations. Since alternative cell arrangements may produce different MSIS values, sensitivity analyses were also examined using alternative plausible arrangements.

The nine normalized variables were arranged in the analysis as follows in Table 1.

| Dimension | Risk / Threat | Control / Protection | Agency / Avoidance |
|---|---|---|---|
| **Cognitive** | Low perceived likelihood of developing skin cancer (MM01ChanceGetCancerS) | Low belief that skin cancer development can be slowed or disrupted (MM05dSlowDownCancerS) | Low belief that behavior or lifestyle contributes to cancer (MM05eBehaviorCauseCancerS) |
| **Affective** | Frequency of skin cancer worry (MM03FreqWorryCancerS) | Feeling that there are too many cancer-prevention recommendations (MM05bTooManyRecommendationsS) | Reluctance to be checked for skin cancer because of fear (MM05hCheckCancerAfraidS) |
| **Behavioral** | Indoor tanning frequency (SP02TanningDevices) | Sunscreen nonuse (SP01aSunscreen) | Shade nonuse (SP01bShade) |

Table 1. Structure of the 3x3 Magic-Square-Inspired Skin Cancer Prevention Model. All nine variables were recoded and normalized to a common scale from 0 to 1. Higher values represented greater prevention vulnerability, psychological barriers, or risky behavior. The three rows showed cognitive, affective, and behavioral dimensions. Columns represented related aspects of risk/threat,

control/protection, and agency/avoidance. Row, column, and diagonal means were used to calculate the magic-square imbalance score (MSIS).

For each participant, the mean of three rows, three columns, and two diagonals were calculated. This produced eight line means $L_1$ through $L_8$. The magic-square imbalance score (MSIS) was calculated by using the following formula:

$$MSIS = 100\sqrt{\frac{1}{8}\sum_{k=1}^{8}\left(L_k - \overline{L}\right)^2}$$

An MSIS of 0 showed perfect equality among the eight lines. The higher the values were, the greater the cognitive-affective-behavioral imbalance was. The score was not interpreted as a clinical skin cancer risk score but as an exploratory behavioral measure. The MSIS was designed as a formative exploratory index rather than a conventional psychometric scale. The nine components of it represent distinct cognitive, affective, and behavioral domains and were not assumed to measure a single underlying construct. Therefore, internal consistency statistics such as Cronbach's alpha were not treated as primary measures of reliability. Instead, quantifying structural imbalance across conceptually different domains using a consistent 0 – 1 normalization and the same row, column, and diagonal calculation for all participants was the purpose of the MSIS. The Protection Index was derived from the behavioral component of the model. Higher values represent stronger protective behavior. Due to the contribution of sunscreen nonuse, shade nonuse, and indoor tanning to the MSIS, the Protection Index was not treated as an independent validation measure. Its comparison with MSIS was used only to explain how overall imbalance corresponded with the behavioral component of the same framework.

**Statistical Analysis**

Using the HINTS final sample weight (FWGT), survey estimates were weighted. Then, 50 jackknife replicate weights (FWGT1-FWGT50) were used to calculate standard errors. Then, weighted descriptive statistics, MSIS tertiles, protection scores, demographic comparisons, and survey-weighted regression models were calculated. In the adjusted regression analysis, the Protection Index was treated as the outcome variable. Cognitive-affective discordance and psychological adversity were evaluated as principal predictors, while age, sex, education, and race/ethnicity were included as demographic covariates. To evaluate the magnitude and statistical uncertainty of the associations, regression coefficients, 95% confidence intervals, and p-values were used. Due to the nature of a cross-sectional design of this study, all findings were not interpreted as causal relationships but as associations. As the MSIS is a newly proposed measure, the analysis in this study was considered an initial exploratory application rather than a formal validation study. Therefore, associations between MSIS and prevention-related behavioral measures were interpreted as preliminary evidence of construct relevance, not as proof of reliability or validity.

## Results

A total of 1,279 adults from the HINTS 2005 skin cancer module with valid responses for all nine cognitive, affective, and behavioral variables used in the magic-square model were included in the complete-case analysis. The weighted mean age of the sample was 42.6 years (SE = 0.7). Around 50.3% were male, and 49.7% were female. In addition, 35.4% were people in the age from 18 to 34, 32.1% were in the age from 35 to 49, 20.4% were in the age from 50 to 64, and 12.0% were in the age at 65 years or older. The weighted sample was 68.1% non-Hispanic White, 14.1% Hispanic, 11.2% non-Hispanic Black, and 6.6% from other racial groups.

After observing several cognitive and affective barriers to skin cancer prevention, around 51.8% of respondents reported to have perceived their chance of developing skin cancer as low or somewhat low, and 36.0% reported worrying about skin cancer sometimes, often, or all the time. In addition, 42.0% agreed that there were too many cancer prevention recommendations, and 16.1% agreed that they were reluctant to be checked for skin cancer due to fear. In terms of prevention beliefs, 14.0% reported to disagree that skin cancer development may be slowed or disrupted, and 29.3% reported to disagree that both behavior and lifestyle contributed to cancer development.

Preventive behaviors reported to considerably vary. Only 26.7% of respondents reported that they used sunscreen when outside on sunny days always or often. 41.8% reported that they sought shade always or often. Around 8.1% reported to use an indoor tanning device during the previous 12 months. The weighted mean cognitive vulnerability score reported 36.1, compared with 24.5 for affective barriers and 36.4 for behavioral vulnerability. The mean overall vulnerability reported 32.3, and the mean Protection Index reported 63.6. With the newly constructed magic-square imbalance score (MSIS), a weighted mean of 17.4 (SE = 0.2), a median of 17.4, and an observed range from 4.0 to 28.6 were reported. The full key weighted results from the HINTS 2005 analysis are summarized in Table 2.

| Measure | Weighted Result |
|---|---|
| Complete-case sample size | 1,279 |
| Mean age, years (SE) | 42.6 (0.7) |
| Male | 50.3% |
| Female | 49.7% |
| Low or somewhat low perceived skin cancer risk | 51.8% |
| Worries about skin cancer at least sometimes | 36.0% |
| Reports too many cancer prevention recommendations | 42.0% |
| Fear-based reluctance to skin cancer examination | 16.1% |
| Disagrees that skin cancer development can be slowed or disrupted | 14.0% |
| Disagrees that behavior or lifestyle contributes to cancer | 29.3% |
| Always or often uses sunscreen | 26.7% |
| Always or often seeks shade | 41.8% |

| | |
|---|---|
| Any indoor tanning in previous 12 months | 8.1% |
| Mean cognitive vulnerability score | 36.1 |
| Mean affective barrier score | 24.5 |
| Mean behavioral vulnerability score | 36.4 |
| Mean overall vulnerability score | 32.3 |
| Mean Protection Index | 63.6 |
| Mean Magic-Square Imbalance Score (MSIS), SE | 17.4 (0.2) |
| Median MSIS | 17.4 |
| Observed MSIS range | 4.0–28.6 |
| Protection Index: low-MSIS tertile | 71.8 |
| Protection Index: middle-MSIS tertile | 62.7 |
| Protection Index: high-MSIS tertile | 56.2 |

Table 2. Weighted Descriptive Results for Skin Cancer Prevention and Magic-Square Imbalance Measures. Using the HINTS 2005 final sample weight, estimates were weighted. MSIS = magic-square imbalance score; higher MSIS values represent greater imbalance among cognitive, affective, and behavioral dimensions. Higher protection index values show stronger skin cancer protective behavior.

There was a clear graded pattern observed across MSIS tertiles. There was a decrease in mean protection index from 71.8 (SE = 0.8) in the low-imbalance group to 62.7 (SE = 0.9) in the middle group and 56.2 (SE = 1.6) in the high-imbalance group (Figure 1). Since the Protection Index and MSIS share behavioral components, this graded pattern should not be interpreted as evidence of an independent predictive relationship but descriptively. In addition, there was an increase reported in sunscreen non-use from 47.0 to 65.2 to 71.5. Furthermore, there was also an increase reported in shade non-use from 35.6 to 42.1 to 52.1. Tanning exposure also reported an increase from 2.0 in the low-imbalance group to 7.9 in the high-imbalance group. For the observed educational differences, mean MSIS decreased from 19.4 among adults with less than a high school diploma to 15.6 among college graduates (Figure 2). In the adjusted regression analysis, cognitive-affective discordance was not significantly associated with the Protection Index (B = 0.002, p = 0.931). However, greater psychological adversity was significantly associated with lower protection (B = -0.109, 95% CI [-0.215, -002], p = 0.046). Female sex (B = 5.392, p = 0.001), college graduation (B = 7.712, $p < 0.001$), and older age (B = 1.284 per 10 years, p = 0.005) were associated with higher Protection Index scores.

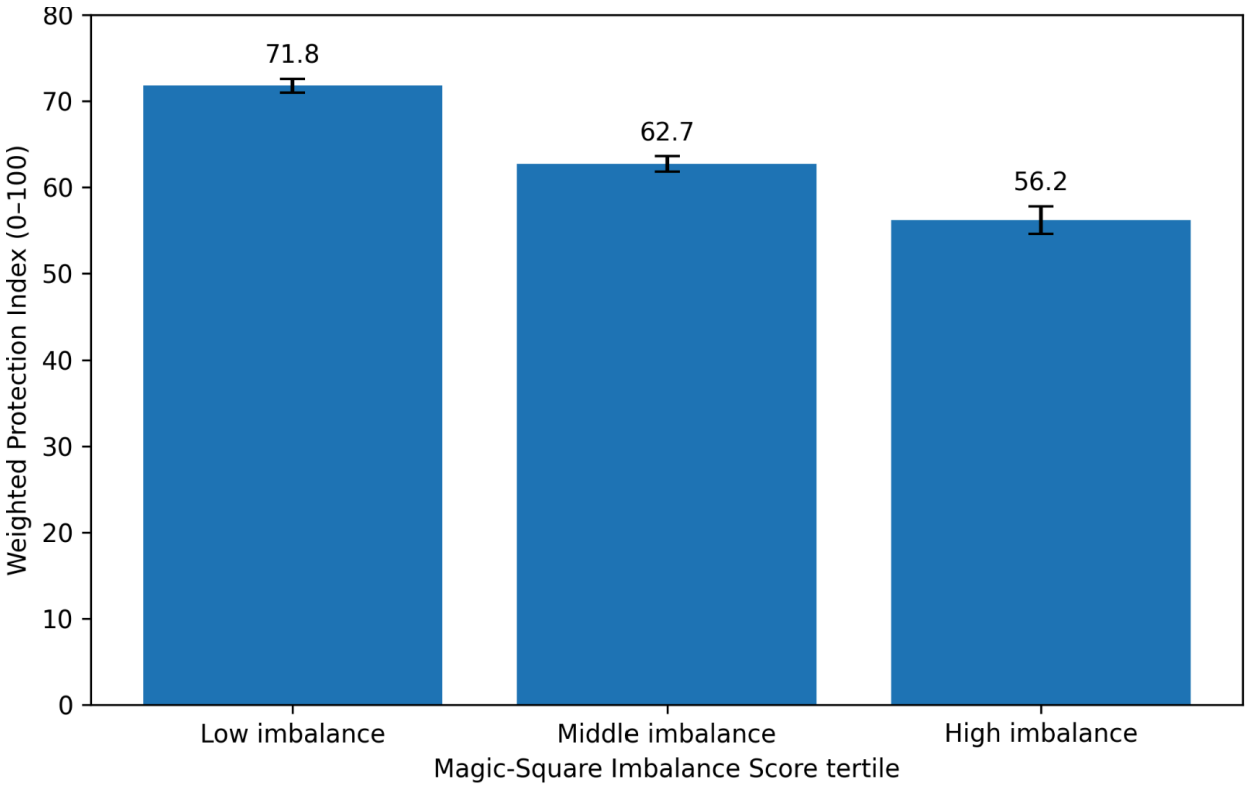



Figure 1. Protection Index Across Magic-Square Imbalance Groups. Weighted protection index across low-, middle-, and high-Magic-Square Imbalance Score (MSIS) tertiles. As imbalance increased, protection decreased progressively.

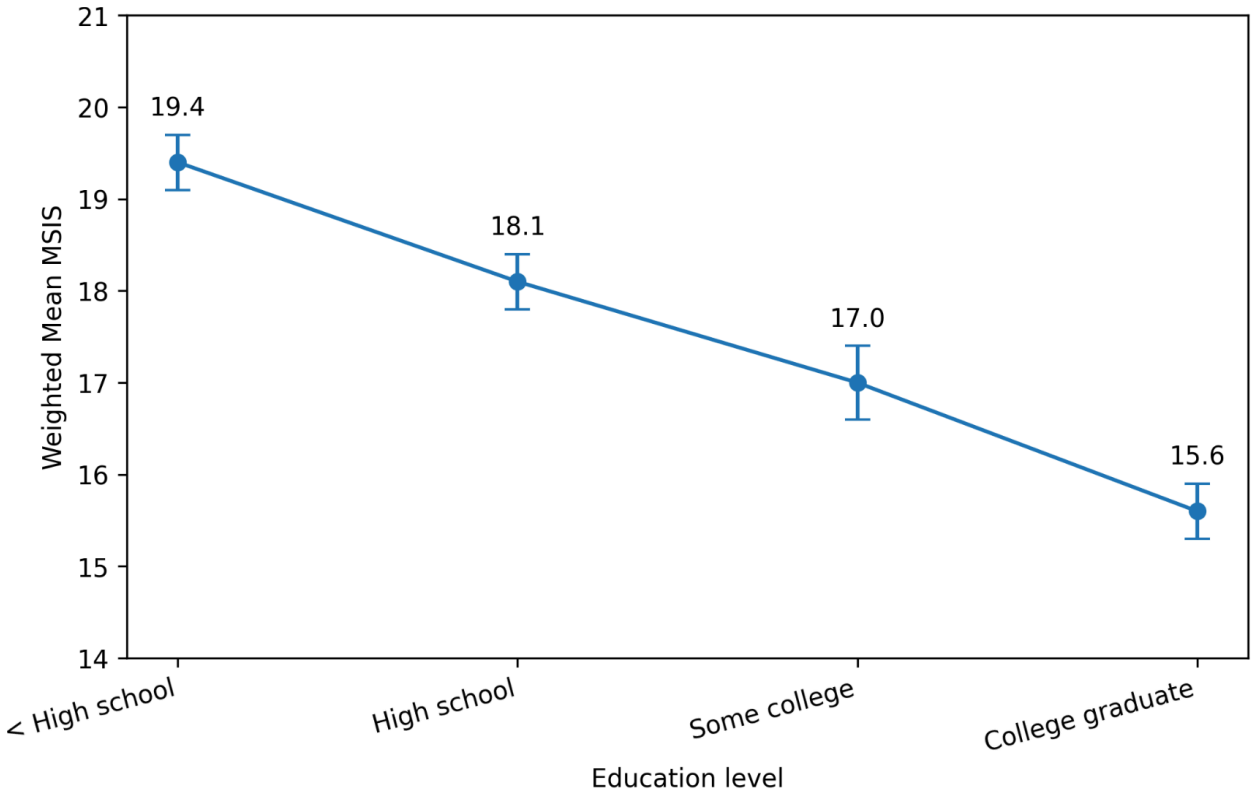



Figure 2. Magic-Square Imbalance Score by Education Level. Greater educational attainment was associated with lower cognitive-affective-behavioral imbalance.

## DISCUSSION

The findings in this study suggest that cognitive, affective, and behavioral factors do not always operate in a balanced manner in relation to skin cancer prevention. Substantially lower protection index scores were reported among participants, showing a decrease from 71.8 in the low-imbalance group to 56.2 in the high-imbalance group. Greater sunscreen non-use, shade non-use, and tanning exposure were associated with higher imbalance. What these results suggest is that identifying individuals with weaker overall prevention profiles may be supported by imbalance across risk perception, emotional response, and protective behavior. These descriptive findings supported the proposed hypothesis. However, as the MSIS and Protection Index share behavioral components, the observed relationship should not be interpreted as independent validation of the MSIS.

A more nuanced interpretation was provided by the regression results. There was no independent association between cognitive-affective discordance alone with skin cancer protection, and lower skin cancer protection was associated significantly with greater psychological adversity. What these findings suggest is that there exists a much more complex relationship between thoughts, emotions, and preventive

action than a single mismatch between cognition and affect. Demographic differences were also significant. Higher protection scores were obtained among women, older adults, and college graduates. However, greater MSIS was associated with lower education. These findings suggest that differences in health literacy, access to prevention information, and broader socioeconomic factors may be reflected by behavioral imbalance.

In spite of aforementioned findings, there are several limitations of this study. First, this study used HINTS 2005 that was cross sectional. Therefore, no causal relationships were established. Second, all measures were self-reported and, hence, may be influenced by recall or social-desirability bias. Third, only a survey subgroup was administered with the skin cancer questions, and this has reduced the final complete-case sample to 1,279 participants. Fourth, the MSIS is a newly developed exploratory measure and has not undergone formal external validation, test-retest reliability assessment, or comparison with an independently validated measure of cognitive-affective-behavioral imbalance. Therefore, the numerical values and cutoffs used in this study should not be interpreted as established clinical or psychometric thresholds. It is recommended for future studies to evaluate the robustness of the MSIS using alternative variable arrangements, independent datasets, and external health-behavioral measures before the score is treated as a validated index. In addition, the Protection Index contains behavioral information overlapping with variables incorporated into the MSIS. Therefore, it created partial conceptual dependence between the two measures. Therefore, their association should be viewed as descriptive. Furthermore, future studies should validate MSIS against an independent behavioral outcome. Lastly, only behavioral and psychological processes were represented by the model, not a direct neurological activity. Therefore, the findings should not be interpreted as evidence of underlying brain mechanisms.

## CONCLUSION

In this study, a magic-square-inspired mathematical model was developed to examine cognitive-affective-behavioral imbalance in skin cancer prevention among adults in the U.S. using HINTS 2005 data. The findings suggest that participants with higher magic-square imbalance scores generally reported weaker protective behavior, including less frequent sunscreen use and shade-seeking and greater tanning exposure. With noticeable decline in the protection index across increasing imbalance groups, it has been suggested that inconsistency among risk perception, emotional response, and behavior may help identify less protective prevention profiles. Psychological adversity and several demographic factors were significantly associated with prevention behavior even though cognitive-affective discordance alone was not an independent predictor of protection. These findings show that a quantitative framework traditionally used to study numerical balance may be adapted to examine health behavior. It is recommended for future study to validate the imbalance score in newer populations, while exploring whether similar mathematical models may be applied to other cancer-prevention or health-behavior areas.

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