Neuropsychological Effects of Konzo: A Neuromotor Disease Associated With Poorly Processed Cassava

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KEY WORDS

konzo, children, Africa, neuropsychology, motor neuron disease, memory, motor function, cognitive ability, cassava

ABBREVIATIONS

BOT-2—Bruininks-Oseretsky Test of motor proficiency (second edition)

CI—confidence interval

CNS—central nervous system

HOME—Home Observation for Measurement of the Environment

KABC-II—Kaufman Assessment Battery for Children (second edition)

MPI—mental processing index

OR—odds ratio

WHO—World Health Organization

Dr Boivin participated in the design of the study, oversight of neuropsychological exam, analysis of the data, and drafting of manuscript. Drs Okitundu, Bumoko, and Sombo participated in the field testing of the children and drafting of the manuscript. Dr Mumba participated in the study design, konzo diagnosis, and clinical analysis. Dr Tylleskar participated in the design of study, analysis plan, and drafting of the manuscript. Dr Page participated in the statistical analysis and tables, interpretation of study findings, and drafting of the manuscript. Dr Tamfum-Muyembe participated in the study design, served as Democratic Republic of Congo co-principal investigator, and participated in the clinical analysis. Dr Tshala-Katumbay was the study principal investigator, and participated in the design of study, oversight of neurologic examination, and drafting of the manuscript. All authors approved the final manuscript as submitted.

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WHAT'S KNOWN ON THIS SUBJECT: Konzo is an irreversible sudden-onset upper-motor neuron disorder affecting children dependent on bitter cassava for food. The neuroepidemiology of konzo is well characterized. Children subsisting on poorly processed bitter cassava without adequate dietary sulfur-based amino acids are especially at risk.

WHAT THIS STUDY ADDS: We found a pervasive subclinical neurocognitive effect in children with konzo. This study provides the first evidence we are aware of that a motor proficiency examination can effectively characterize konzo severity.

abstract

BACKGROUND: Konzo is an irreversible upper-motor neuron disorder affecting children dependent on bitter cassava for food. Although the neuroepidemiology of konzo is well characterized, we report the first neuropsychological findings.

METHOD: Children with konzo in the Democratic Republic of Congo (mean age 8.7 years) were compared with children without konzo (mean age 9.1 years) on the Kaufman Assessment Battery for Children, second edition (KABC-II), and the Bruininks-Oseretsky Test of Motor Proficiency, second edition (BOT-2). Both groups were also compared with normative KABC measures from earlier studies in a nearby nonkonzo region.

RESULTS: Using a Kruskal-Wallis test, children with konzo did worse on the KABC-II simultaneous processing (visual-spatial analysis) ($K [1] = 8.78, P = .003$) and mental processing index (MPI) ($K [1] = 4.56, P = .03$) than children without konzo. Both konzo and nonkonzo groups had poorer KABC sequential processing (memory) and MPI relative to the normative group from a nonkonzo region ($K [2] = 75.55, P < .001$). Children with konzo were lower on BOT-2 total ($K [1] = 83.26, P < .001$). KABC-II MPI and BOT-2 total were predictive of konzo status in a binary logistic regression model: odds ratio = 1.41, $P < .013$; 95% confidence interval 1.13–1.69.

CONCLUSIONS: Motor proficiency is dramatically affected, and both children with and without konzo have impaired neurocognition compared with control children from a nonoutbreak area. This may evidence a subclinical neurocognitive form of the disease, extending the human burden of konzo with dramatic public health implications. *Pediatrics* 2013;131:e1231–e1239

Konzo is a nonprogressive upper-motor neuron disorder documented in African rural areas that are dependent on bitter cassava (manioc), which produces edible carbohydrates in ecologically degraded zones. Bitter cassava is usually soaked for fermentation, and/or sufficiently sun dried to allow for breakdown of linamarin and its cyanogenic compounds. When cassava coquettes are not sufficiently processed (eg, in times of drought or armed conflicts),^{1,2} outbreaks of konzo may occur. Populations are especially vulnerable if shortcuts in processing the cassava are combined with a low dietary intake of sulfur amino acids needed for the detoxification of cyanide in the human body.³

Konzo is defined by World Health Organization (WHO) as a visible symmetric spastic abnormality of gait while walking or running (Fig 1), with a history of onset of <1 week followed by a nonprogressive course in a formerly healthy person and

bilaterally exaggerated knee or ankle jerks without signs of disease of the spine.⁴ Because konzo is a pure upper-motor neuron disorder, cognitive effects were deemed absent or minimal.^{4,5} This study is the first to evaluate whether konzo affects neuropsychological function.

METHOD

Study Site

The Ministry of Health for the Democratic Republic of Congo and the institutional review board for Oregon Health and Sciences University provided study approval. Caregivers of study children were consented orally in the local language with signature or thumb print for those not literate. The study site was a konzo outbreak zone in the district of Kahemba, southern Bandundu Province, Democratic Republic of Congo, in October to November 2011. Kahemba town has a population of ~50 000, whereas the

surrounding area has a population of ~250 000. Residents rely heavily on cassava farming and possess limited livestock for subsistence. This region has been continuously affected by konzo since 1990,⁶ and prevalence is as high as 20% in some villages.⁷⁻⁹

Study Sample

From earlier outbreaks in Kahemba, 5000 subjects in Kahemba town had been listed on a WHO surveillance list. From this list, we were able to locate a total of 308 eligible children with konzo in Kahemba town, and these children comprised our study population. From this population, 123 children with konzo were randomly selected for study participation (65 boys, 58 girls; mean age 8.7 years; range 4 to 17 years). Sample size was based on an 80% power calculation for a 2-sided test (.05 level of significance) to detect Kaufman Assessment Battery for Children (second edition) (KABC-II) and Bruininks-Oseretsky Test of motor proficiency (second edition) (BOT-2) global performance differences equal to 0.25 SD between konzo and age-matched control groups.¹⁰ For all study children with konzo, neurologists did a neurologic examination to confirm konzo diagnosis using the 1996 WHO criteria.⁴ Height and weight were also measured at the time of the neurologic evaluation (Table 1).

For each child with konzo, we attempted to consent a comparison child without konzo (1996 WHO criteria) within 2 years of age, from a neighboring household that met inclusion criteria. Children with a medical history of hospitalization for illness possibly affecting the central nervous system (CNS) (eg, cerebral malaria) were excluded. In total, 87 children without konzo (52 boys, 35 girls; mean age 9.1 years; range 4 to 15 years, Table 1) met the criteria to participate in the study, and completed neuropsychological assessments. The study design was an observational

FIGURE 1

Child and mother affected by konzo in the Democratic Republic of Congo. Photograph by Thorkild Tylleskar.

TABLE 1 Subject Characteristics for Children With and Without Konzo

	Konzo	Nonkonzo	<i>P</i> Value ^a
No. subjects	123	87	
Age, y, mean (SD)	8.7 (2.5)	9.1 (2.6)	.212
Female gender, n (%)	35 (47)	58 (40)	.320 ^b
Enrolled in school, n (%)	73 (59)	78 (90)	<.001 ^{b,g}
Caldwell HOME score, z-score	−0.1 (−0.7–0.6)		
School grade level, mean (SD)	1.3 (1.6)	2.5 (1.9)	<.001 ^g
Caregiver with konzo, n (%)	99 (81)	58 (66)	.023 ^{b,g}
Other family with konzo, n (%)	85 (85)	61 (70)	.007 ^{b,g}
Weight for age, CDC z-score ^c	−2.9 (−1.0)	−2.1 (1.5)	<.001 ^g
Height for age, CDC z-score	−3.4 (1.4)	−2.3 (1.8)	<.001 ^g
Mid-upper arm circumference, cm	15.2 (1.9)	15.7 (1.9)	.122
Head circumference, cm	49.8 (1.7)	50.2 (1.8)	.178
Caldwell HOME score, total ^d	43.5 (8.1)	47.2 (10.4)	.016 ^g
Socioeconomic status score ^e	2.2 (1.1)	2.8 (3.2)	.645
Neurologic index score ^f	11.4 (4.4)	2.0 (1.7)	<.001 ^g

CDC, Centers for Disease Control and Prevention. Group means and SDs (in parentheses) are presented unless otherwise specified.

^a *P* values based on Kruskal-Wallis analysis of variance test unless otherwise specified.

^b *P* values for χ^2 statistic between categories (gender, enrolled in school).

^c z-score values are from CDC 2000 norms from Epi Info@.

^d Based on the Caldwell HOME total score.

^e The socioeconomic status score is measured by evaluating the physical characteristics of home dwelling and material and animal possessions during a visit to the home.

^f Children with konzo and control children were evaluated for upper-motor neuron signs, which are characteristic of konzo (Table 2). From this examination we computed a total score reflecting the neurologic impairment pertaining to konzo. For each of the neurologic signs listed in Table 2, children were scored as either normal (0 points), mildly abnormal (1 point), or moderately/severely abnormal (2 points).

^g Statistically significant *P* values.

study for a cross-sectional 1-time comparison of disease and control groups on neuropsychological outcomes.

All children were screened for retroviruses HIV-1 and -2, and human T-lymphotropic virus-I, and none were positive. Urinary thiocyanate (Bradbury kit, 1999; http://biology.anu.edu.au/hosted_sites/CCDN/five.html) was also measured in all study children ($518.59 \pm 354.19 \mu\text{M/mL}$ for the konzo group and 381.04 ± 221.88 for controls). These are high levels of cyanogenic exposure in both groups based on earlier studies by Banea et al of thiocyanate levels among konzo-affected populations in this region.^{7,8}

Socioeconomic Status and Caldwell Home Observation for the Measurement of the Environment

After consent and enrollment, a nurse visited the home of each study child to complete the middle childhood version of the Caldwell Home Observation for the Measurement of the Environment

(HOME).¹¹ This is used to assess the stimulation and learning opportunities offered by the child's home environment. The nurse also completed an evaluation of the socioeconomic condition of the home.^{10,12,13} This measure scored a dwelling on the basis of type of floor, roofing, wall structure (eg, mud and wood or cement/brick), cooking facilities, toilet facilities, water source or plumbing, electricity/appliances, and material possessions.

Neurologic Index of Konzo Severity

Children with konzo and control children were evaluated for upper-motor neuron signs that are characteristic of konzo (Table 2). From this examination we computed a total score reflecting the konzo neurologic impairment. Quantifying the neurologic severity of the disease allowed us to statistically evaluate its relationship to our cognitive (KABC-II) and motor proficiency (BOT-2) measures. For each of the neurologic signs listed in Table 2, children were scored as

either normal (0 points), mildly abnormal (eg, periodic or mild hyperreflexia and exaggerated clonus or reflexive delay; 1 point), or moderately/severely abnormal (eg, highly exaggerated and/or sustained hyperreflexia or clonus, or sustained reflexive delay; 2 points).

KABC-II

The KABC provides a comprehensive evaluation of core neurocognitive performance domains (see <http://ego.the-chicagoschool.edu/s/843/index.aspx?sid=843&gid=63&pgid=2050> for powerpoint presentations describing the KABC-II). It has been used previously in the Democratic Republic of Congo,^{10,12–16} and it has been validated in Uganda.¹⁷ Neuropsychological evaluation took place in a quiet room near Kahemba Hospital that afforded privacy.

Normative Memory Measures (KABC, First Edition)

The KABC, first edition, was used in validation and intestinal parasite treatment studies in central Bandundu in Kikongo, an area where no konzo has been reported.^{12,13,16} Kikongo is in a remote rural area on the Wamba River 200 km northwest of the Kahemba outbreak study site. KABC memory subtest and global scores were used from these combined samples as a normative reference base (Kikongo normative group) to compare with the Kahemba children with and without konzo.

The Kikongo normative sample consisted of 132 boys and 118 girls ranging from 4 to 13 years of age (mean = 8.7 years, SD = 1.7 years). The Kikongo children were also dependent on bitter cassava as their primary food staple, with no other major food crops. However, because of a public health education program in Kikongo, safer processing methods of cassava were generally used and no outbreaks of konzo had been reported. This training program for pastors and their wives and other

TABLE 2 Neurologic Tests for Upper-Motor Neuron Disease

Neurologic Signs	Nonkonzo	Konzo	Φ Coefficient
	<i>n</i> = 87	<i>n</i> = 123	
Patellar reflex	48.3% (42)	0.8% (1)	0.716***
Ankle reflex	60.9% (53)	2.4% (3)	0.680***
Babinski's reflex	79.3% (69)	30.1% (37)	0.486***
Chin-palm reflex	80.2% (69)	69.1% (85)	0.124*
Oppenheim's sign	82.8% (72)	75.6% (93)	0.098*
Brachial reflex	89.7% (78)	34.1% (42)	0.553***
Biceps reflex	92.0% (80)	27.6% (34)	0.636***
Ankle clonus	96.6% (84)	50.4% (62)	0.495***
Speech difficulties	98.9% (86)	58.5% (72)	0.460***
Blurred vision	98.9% (86)	86.2% (106)	0.223**
Patellar clonus	98.9% (86)	97.6% (120)	0.062*
Nystagmus	98.9% (86)	86.2% (106)	0.223***
Somatic sensitivity loss	100% (87)	97.6% (120)	0.101*

The tests comprised our neurologic index measures (Table 1). Between-group comparisons consist of konzo groups (nonkonzo, konzo). The neurologic tests are ordered from top to bottom on the basis of the test that had the lowest percentage of normal results in the nonkonzo group (number of children with normal reflex in parentheses). The high percentage of abnormal findings with patellar and ankle reflexes in children without konzo, combined with a very low percentage of normal findings in the children with konzo. * $P < .05$, ** $P < .01$, *** $P < .001$ on Φ coefficient test of relationship between group (konzo or nonkonzo) and percent normal on that neurologic test.

community leaders was implemented at the pastoral training institute in Kikongo, with sponsorship by the American Baptist Missions.¹⁰

In terms of age, gender, and socioeconomic status score, the Kikongo sample did not significantly differ from the Kahemba samples, as described in Table 1. HOME scores were not available for the Kikongo children; however, only 4.8% of the Kikongo children were not in school, compared with the children with konzo (40.7%) and without konzo (10.2%) in Kahemba. The WHO weight-for-age z-scores for the Kikongo children (mean = -1.75 , SD = 1.0) were significantly higher than those of the Kahemba children both with konzo ($P < .001$) and without ($P = .016$).

BOT-2

The BOT-2 is a comprehensive test of motor proficiency. Composite scores include fine manual control, manual coordination, body coordination, strength and agility, and a total composite score. The BOT-2 has proven adaptable and useful in characterizing the specific aspects of motor impairment associated with HIV in Ugandan children.^{18,19}

Statistical Analysis

The Kruskal-Wallis 1-way analysis of variance was used for a nonparametric evaluation of between-group differences (nonkonzo versus konzo; or differences among nonkonzo, konzo, and Kikongo normative groups). Neurologic index was correlated to the BOT-2 and KABC-II global measures by group using a Pearson product-moment correlation coefficient test. A binomial logistic regression analysis was used to evaluate the predictive significance of KABC-II total global performance (mental processing index; MPI) and BOT-2 total motor proficiency on nonkonzo versus konzo group status. SPSS version 19 (IBM SPSS Statistics, IBM Corporation, Armonk, NY) was used for statistical analyses and graphs.

RESULTS

Between-Group Descriptive Differences

The konzo and nonkonzo groups were similar in age, gender composition, and socioeconomic status as measured by material possessions in the home; however, the children with konzo were less likely to be enrolled in school ($\chi^2 [1] = 23.17$, $P < .001$). Children with konzo were more likely to have a care-

giver, usually the mother, with konzo ($\chi^2 [1] = 5.16$, $P = .023$), and another family member in the household with the disease ($\chi^2 [1] = 7.16$, $P = .007$).

Children both with and without konzo were significantly below Centers for Disease Control and Prevention normative weight-for-age and height-for-age norms, with the children with konzo lower than the nonkonzo group on both weight ($K [1] = 15.55$, $P < .001$) and height ($K (1) = 19.94$, $P < .001$) (Table 1). The konzo group was also lower on Caldwell HOME scale total score measuring quality of caregiving ($K [1] = 5.81$, $P = .016$).

Between-Group KABC-II Differences

Children without konzo were better than children with konzo on the KABC-II global measures of simultaneous processing ($K [1] = 8.78$, $P = .003$) and the MPI measure of global cognitive performance ($K [1] = 4.56$, $P = .033$) (Table 3). Other KABC-II global domains had individual subtests that significantly differed between groups, with P values in bold in Table 3. Table 3 also shows group medians and interquartile ranges for all the KABC-II global scale and subtest measures. When stratifying the between-group differences by gender, all of the statistically significant between-group differences for the KABC-II were consistent for the boys. There were no significant differences between the groups of girls with and without konzo (Table 3).

The nonkonzo and konzo groups were compared with normative group data from Kikongo. The Kikongo control group was significantly better than the nonkonzo and konzo groups on the KABC sequential processing global measure ($K [2] = 75.55$, $P < .001$), simultaneous processing ($K [2] = 12.71$, $P = .002$), and MPI global cognitive performance ($K [2] = 91.57$, $P < .001$). In Fig 2, box and whisker plots are used to visually depict these differences among the 3 groups (nonkonzo, konzo, normative control).

TABLE 3 Kruskal-Wallis ANOVA Test for Independent Samples Is Used for the Between-Group Comparisons for Konzo Group (Konzo, Nonkonzo)

KABC-II Standardized Global Scales and Their Subtests, and BOT-2 Standardized Global Scales	Konzo Groups Median (Interquartile Range)		Kruskal-Wallis ANOVA <i>K</i> Score	Kruskal-Wallis <i>P</i> Values for Between-Group Konzo/Nonkonzo Comparisons for All and by Gender		
	Nonkonzo	Konzo		<i>P</i> All	<i>P</i> Female	<i>P</i> Male
	<i>n</i> = 87	<i>n</i> = 123	<i>df</i> = 1	<i>n</i> = 210	<i>n</i> = 93	<i>n</i> = 117
KABC-II sequential processing	74 (22)	71 (17)	2.73	.098	.193	.430
Number recall	7 (5)	6 (5)	1.05	.306	.441	.439
Word order	4 (4)	3 (3)	4.40	.036 ^a	.063	.017 ^a
Hand movements	4 (4)	6 (4)	3.14	.077	.236	.035 ^a
KABC-II simultaneous processing	64 (16)	58 (16)	8.78	.003 ^a	.501	.003 ^a
Face recognition ^b	8 (6)	5 (6)	15.90	<.001 ^a	.362	<.001 ^a
Rover	7 (6)	5 (6)	8.31	.004 ^a	.478	.589
Triangles	1 (2)	1 (1)	3.34	.068	.540	.543
KABC-II learning	70 (14)	70 (11)	0.30	.582	.596	.875
Atlantis	5 (3)	5 (3)	0.11	.738	.974	.923
Rebus	4 (3)	4 (4)	1.02	.312	.231	.112
KABC-II delayed learning	72 (14)	74 (14)	0.19	.666	.646	.257
Atlantis delayed	5 (3)	5 (3)	2.09	.149	.800	.854
Rebus delayed	4 (3)	4 (4)	1.19	.275	.317	.464
KABC-II planning	57 (11)	51 (16)	3.71	.054	.742	.037 ^a
Conceptual thinking ^b	8 (7)	6 (8)	6.18	.013 ^a	.836	.002 ^a
Pattern recognition	2 (2)	1 (2)	2.24	.135	.899	.975
KABC-II MPI	60 (14)	58 (13)	4.56	.033 ^a	.420	.087
BOT-2 fine motor control	32 (13)	29 (12)	8.44	.004 ^a	.146	.032 ^a
BOT-2 manual coordination	36 (10)	26 (10)	58.30	<.001 ^a	<.001 ^a	<.001 ^a
BOT-2 body coordination	40 (15)	25 (10)	111.43	<.001 ^a	<.001 ^a	<.001 ^a
BOT-2 strength and agility	38 (9)	24 (11)	104.13	<.001 ^a	<.001 ^a	<.001 ^a
BOT-2 Motor Proficiency Total	34 (10)	22 (9)	83.26	<.001 ^a	<.001 ^a	<.001 ^a

Group medians and interquartile ranges are presented for the nonkonzo and konzo groups for the KABC-II standardized (age-adjusted) global scales and their corresponding subtests, as well as for the BOT-2 standardized (adjusted for age and gender) global scales. The Kruskal-Wallis test *P* values for the nonkonzo/konzo between-group comparisons are also stratified by gender (far right-hand columns). ANOVA, analysis of variance.

^a Statistically significant *P* values.

^b KABC-II subtest raw score used because scaled scores only available for children <7 years.

Kikongo control group subtest normative data were available only for the KABC sequential processing domain for comparison with the Kahemba nonkonzo and konzo groups. Kikongo children had better memory than the nonkonzo and konzo groups on the KABC sequential processing subtests of hand movements ($K[2] = 93.49$, $P < .001$), number recall ($K[2] = 33.69$, $P = .001$), and word order ($K[2] = P < .001$). For KABC global and memory subtest comparisons, the Kikongo control group performed above both the nonkonzo and konzo groups (see Fig 2).

Between-Group BOT-2 Differences

Children without konzo had higher motor proficiency measures on BOT-2 fine motor control ($K[1] = 8.44$, $P = .004$), manual coordination ($K[1] = 58.30$, $P < .001$), body coordination ($K[1] = 111.43$,

$P < .001$), strength and agility ($K[1] = 104.13$, $P < .001$), and motor proficiency total ($K[1] = 83.26$, $P < .001$). BOT-2 differences between the children with and without konzo were significant for both genders (see Table 3).

Relationship of Neurologic Index to BOT-2 and KABC-II

For the children with konzo, total neurologic signs was highly correlated with BOT-2 total score ($r[122] = -0.433$, $P < .0001$). Although total neurologic signs was significantly correlated with all 4 BOT-2 global domains, it has the weakest correlation coefficient with fine manual control ($r[122] = -0.225$, $P = .012$), and the strongest correlation with body coordination ($r[122] = -0.559$, $P < .0001$) and strength and agility ($r[122] = -0.568$, $P < .0001$). Correlations for the control children were significant only

for body coordination ($r[86] = -0.249$, $P = .02$).

The neurologic index for the children with konzo was significantly correlated only with KABC-II MPI ($r[122] = -0.239$, $P = .008$) and the KABC-II global domain of learning ($r[122] = -0.244$, $P = .006$), and delayed recall ($r[118] = -0.227$, $P = .013$). Neurologic Index was not significantly correlated with any of the KABC-II measures for the children without konzo.

Neuropsychological Predictors of Konzo Group Status

In a binomial logistic regression model, both KABC-II MPI and BOT-2 total motor proficiency significantly predicted konzo group status: odds ratio (OR) = 1.41, $P < .013$; 95% confidence interval (CI) 1.13–1.69; Nagelkerke $R^2 = 0.51$; overall correct classification percentage of 79%. Individually, BOT-2 total

FIGURE 2

Box plots for the kongo groups (nonkongo, kongo) and the Kikongo normative control group by gender for the KABC global scales (sequential processing, simultaneous processing, mental processing index) and memory subtests (hand movements, number recall, word order). Top and bottom of the box at the third and first quartiles, bisected by the median with outliers plotted as individual data points. American normative mean of 100 at dashed line (SD = 15) for standardized global scores, and a normative mean of 10 (SD = 3) for scaled subtest scores.

(OR = 0.77, $P < .001$; 95% CI 0.72–0.83) and KABC-II MPI (OR = 1.06, $P = .015$; 95% CI 1.01–1.12) differentiated between the nonkongo and kongo groups.

DISCUSSION

Overview of Major Findings

Children with kongo did more poorly than children without kongo on KABC-II simultaneous processing (visual-spatial analysis and problem solving) and on MPI global performance. KABC-II global scale and subtest between-group dif-

ferences were significant for the boys, but not the girls. The boys with kongo were also less likely to be enrolled in school, perhaps because of social stigma associated with the disorder.⁵ This may have further contributed to their poorer neurocognitive performance. We are not aware of any published evidence to suggest that boys are more vulnerable to the neuropathophysiological mechanisms of kongo compared with girls. There was not a significant interaction effect between gender and kongo status for

either the Neurologic Index or BOT-2 total motor proficiency measures.

Both kongo and nonkongo groups of children were significantly below KABC normative performance of children from a nonkongo area. These differences were especially apparent on sequential processing (memory) subtests. Weak memory differences between the Kahemba kongo and nonkongo groups may have been because of more pervasive neurocognitive effects from long-term bitter-cassava low-grade toxin exposure in the Kahemba

outbreak area.³ Although there was no reported konzo in our Kikongo communities, we do not have urinary thiocyanate levels or other cassava toxicity biomarkers from this normative sample. Therefore, other factors apart from cassava toxicity may be responsible for the better cognitive performance of these children compared with our Kahemba konzo and nonkonzo samples. Children affected by konzo also had significantly lower anthropometric measures (weight for age, height for age), indicative of malnourishment. This is perhaps related to the poor nutritional intake contributing to risk for konzo,^{2,20,21} and nutritional malabsorption commonly reported with konzo.^{22,23} CNS effects of konzo could be compounded by malabsorption and/or malnutrition leading to thiamine and other micronutrient deficiencies. Thiamine deficiency has been related to many of the CNS signs associated with konzo, including cerebellar dysfunction,²⁴ diffuse electroencephalography slowing and evoked response potential abnormalities,²⁵ and pervasive neurocognitive deficits.²⁶

Most of the caregivers for both the konzo and control groups were affected by konzo, but a higher percentage of caregivers of children with konzo were affected (Table 1). Likewise, a higher proportion of households with children with konzo had other family members affected. Caregivers affected by konzo would also be less able to provide for a quality caregiving environment for children with konzo, explaining the significantly lower HOME scores for this group compared with the nonkonzo group. This is a further significant neurocognitive risk factor for children with konzo.

The BOT-2 examination provided a comprehensive motor proficiency evaluation of the effects of konzo on the study children. It was also highly correlated to a neurologic index of konzo severity. This test quantifies the

extent of motor impairment, and could provide a sensitive neuromotor profile of the severity of konzo. Presently, konzo severity is categorized as mild, moderate, or severe using the 1996 WHO criteria, which is largely based on functional mobility.⁴ This can improve over time, as children develop strategies for overcoming their handicap to become more mobile, independent of neurologic impairment level.²² Again, our neurologic index was highly predictive of BOT-2 motor proficiency, as well as KABC-II learning and global cognitive performance (MPI), for the children with konzo only.

In comparing children with and without konzo with the BOT-2, fine motor control of the upper limbs was comparatively more intact in children with konzo than other global motor proficiency domains, such as strength and agility and body coordination. This is consistent with what is known in terms of the neuromotor pathology of the disease, which primarily involves paraparesis to the lower limbs.^{5,27} The KABC-II MPI and BOT-2 total scores together were significantly predictive of konzo status among our study children.

Evidence for a Subclinical Spectrum for Konzo

Previous electrophysiological studies suggest subclinical deficits in konzo.^{8–29} The structural brain and spinal magnetic resonance image of patients with konzo can appear normal, yet an evoked motor potential response from magnetic brain stimulation can be completely absent.³⁰ Transcranial electrical stimulation and magnetic stimulation fails to evoke motor upper-limb responses in subjects with konzo with preserved voluntary motion.^{27,30}

Although patients with konzo can have normal voluntary movement and strength in their hands and arms, they may still lack normal magnetic evoked response potential to those limbs.³¹

They may also be unable to make fine repetitive and alternating finger and hand movements in the absence of any cerebellar disease.³⁰ These fine motor deficits of the upper limbs are much like the deficits observed with some of the items in the BOT-2 fine manual control global scale in the current study.

Frontal electroencephalography slowing occurs with konzo,³² as do cortical abnormalities of somatosensory evoked potentials,³¹ and abnormalities of visual evoked potentials.²⁸ Because electrophysiological studies failed to find an association between their measures of abnormality and the severity of the disease based on the WHO functioning scheme,^{27,28,30–32} we proposed a neuropsychological evaluation to help gauge konzo severity.

It is possible that the subtle and yet subclinical cassava-associated disease may be progressive in nature even from accumulated exposure to low-grade toxicity. The neuropsychological profile related to long-term toxic cassava exposure may differ only in deficit magnitude from the neuropsychological and neuromotor disabilities that result from abrupt corticospinal damage at konzo onset. Such a profile may differ only in deficit magnitude from the neuropsychological and neuromotor disabilities that result from corticospinal damage related to konzo or from a broader damage.

Nigerian tropical ataxic neuropathy, another cassava-associated neurologic disease, illustrates the possibility of a subclinical disease.³³ Detailed neuropsychological studies, combined with studies of biomarkers of cassava cyanogenic exposure and its biological effects, will help determine whether konzo and tropical ataxic neuropathy are on a cassava-associated continuum of neurodegeneration. The extent of neurologic and neuropsychological impairments at neurologic examination could be used together to anchor biomarker findings.

FIGURE 3

Schematic of the functioning and disability profile in konzo based on the *International Classification of Functioning, Disability and Health*, 2nd edition (ICIDH-2). This figure shows what a neuropsychological assessment can add to this disability-based classification scheme. It contributes by bridging the neurologic severity of the disease (either preclinical or full konzo) with the child's functional status in the community. (Adapted from Tshala-Katumbay D, Eeg-Olofsson KE, Tyllskär T, Kazadi-Kayembe T. Impairments, disabilities and handicap pattern in konzo—a non-progressive spastic para/tetraparesis of acute onset. *Disabil Rehabil*. 2001;23(16):735, Figure 2).

Global Health Importance

Much of sub-Saharan Africa is becoming increasingly dependent on high-yield varieties of cassava that thrive in ecologically degraded zones.⁹ Therefore, it is critical to continue brain/behavior research that will help us better understand its neurotoxic properties. The ability to document the more subtle CNS effects of cyanogenic toxicity comprehensive and sensitive neuropsychological batteries is of major public health importance globally and

more specifically, in African regions dependent on bitter cassava.

CONCLUSIONS

This study is the first systematic attempt to characterize the neuropsychological profile of children subsisting on bitter varieties of cassava as the main source of food. We have not only documented specific domains of neurocognitive deficits in children with konzo, but have presented evidence for more pervasive neurocognitive effects

(eg, memory) for both children with and without konzo from a similar nutritional environment with pervasive risk factors for konzo onset. Our study is an important step in revealing the extent to which konzo extends into foundational neurocognitive domains providing the basis for critical functional domains for children.

A schematic in Fig 3 portrays how neuropsychological assessment can enhance the contextual understanding of konzo for children in the community. This figure was adapted from Fig 2 in Tshala-Katumbay et al.⁵ Neuropsychological assessment can bridge the disease severity with the child's functional status in the community. This model uses a more complete ecological, environmental, agro-economic, and pathophysiological context for understanding konzo.³⁴ This framework can provide for a risk-assessment for konzo, leading to better public health surveillance and earlier detection in communities especially in need of targeted public health interventions to prevent konzo outbreaks.

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