



# The Effect of Waterborne Mercury and Nickel on the ATPases and AChE Activities in the Brain of Freshwater Fish (*Oreochromis niloticus*) Depending on the Ca<sup>2+</sup> Concentrations

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## Article History

Received 26 February 2018  
Accepted 26 April 2018  
First Online 15 May 2018

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## Keywords

Metal  
Calcium  
ATPase  
AChE  
Tilapia

## Abstract

In this study, freshwater fish *Oreochromis niloticus* were exposed to acute (3 days) and chronic (30 days) Hg<sup>2+</sup> and Ni<sup>2+</sup> in differing Ca<sup>2+</sup> levels (15, 30 and 90 mg Ca<sup>2+</sup>/L). In the acute duration 30 µM Ni<sup>2+</sup> and 0.3 µM Hg<sup>2+</sup>, in the chronic duration 10 µM Ni<sup>2+</sup> and 0.03 µM Hg<sup>2+</sup> were tested. At the end of the exposures, activities of ATPase (Total-ATPase, Na<sup>+</sup>/K<sup>+</sup>-ATPase and Mg<sup>2+</sup>-ATPase) and AChE were measured in the brain. There were changes upon Hg<sup>2+</sup> and Ni<sup>2+</sup> effects depending on the Ca<sup>2+</sup> concentration though low dependence on Ca<sup>2+</sup> exposure alone. Decreased activities were recorded after acute metal exposures even at high Ca<sup>2+</sup> concentration. There were variable alterations in ATPase activities whereas AChE activity was mostly altered by Hg<sup>2+</sup> exposure. ATPase and AChE activities were changed in both durations due to metal type and Ca<sup>2+</sup> concentration differences. However, ATPase responses were more affected. Changes in the activities demonstrated the sensitivity of these vital enzymes towards environmental factors. Therefore, there is a potential using of these enzymes as biomarkers on the basis of multi-biomarker attitude in environmental toxicology studies.

## Introduction

Aquatic biota can be affected by metals caused by several anthropogenic activities leading several dysfunctions in key mechanisms of fish metabolism. Among the metals mercury is one of the most toxic metals leading to hematological, osmoregulatory and histopathological changes and also reproductive toxicity as a non-essential metal (Sorensen, 1991; Richetti, et al., 2011). Ambient levels of Hg<sup>2+</sup> (USEPA standard) was given as 0.19 µg/L for freshwaters (USEPA, 1980) and 96 h LC50 values were as 0.22 mg/L in *Oreochromis niloticus* fingerlings (Ishikawa, Ranzani-Paiva, & Lombardi, 2007). On the other hand Ni<sup>2+</sup> is a common metal in most surface waters including both natural and anthropogenic sources and also known as an essential trace metal for normal growth in living organisms. Ni<sup>2+</sup> excess or deficiency can cause a

decrease in the aquatic vertebrate overall fitness (Pane, Richards, & Wood, 2003). Threshold limits have been established for Ni<sup>2+</sup> as 70 µg/L according to the WHO (2008) and the concentration of Ni<sup>2+</sup> can reach up to 2.5 mg/L in contaminated freshwaters (Eisler, 1998). LC<sub>50</sub> value of 36 mg/L nickel chloride was found for *O. niloticus* to evaluate the Ni<sup>2+</sup> toxicity (Abou Hadeed, Ibrahim, El-Sharkawy, Saleh Sakr, & Abd El-Hamed, 2008). Physiological function and tissue alterations can be counted dependent upon the Ni<sup>2+</sup> toxicity (Canli, 1995; Topal et al., 2017). Previous data also confirmed that mercury LC50 values were lower than nickel LC50 values (Brown & Dalton, 1972; Speher et al., 1982).

Physico-chemical properties (salinity, hardness, pH, etc.) affect metal bioavailability by altering the metal uptake in fish (Jorgensen, 2010; Wood, Farrel, & Brauner, 2012). Calcium known as the divalent ion responsible for the freshwater hardness is one of the

most significant abiotic factors. It was demonstrated that  $\text{Ca}^{2+}$  can affect metal toxicity which its reduction is dependent upon the  $\text{Ca}^{2+}$  concentration increase in media as it affects bioavailability of metals (Saglam, Atli, & Canli, 2013; Brix, Schlekot, & Garman, 2017). A negative relationship between increasing water hardness ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) and toxicity of metals to aquatic organisms has been studied for a several divalent metals (Wood, 2012).

Maintenance of the osmotic concentrations of the ions and extracellular fluids are the vital functions of the osmoregulation system. Membrane bound ATPase enzymes have significant roles in osmotic balance, ion regulation and membrane permeability.  $\text{Na}^+/\text{K}^+$ -ATPase (EC 3.6.3.9) transporting the  $\text{Na}^+$  and  $\text{K}^+$  through cell membranes and  $\text{Mg}^{2+}$ -ATPase (EC 3.6.3.2) responsible for the transepithelial  $\text{Mg}^{2+}$  regulation are found to be altered by the exposures of different toxic compounds (Sancho, Fernandez-Vega, Ferrando, & Andreu-Moliner, 2003; Parvez, Sayeed, & Raisuddin, 2006; Atli & Canli, 2011). Measurement of ATPase activities can be useful as an early sign for the osmoregulatory system damage due their variable responses in several metal exposure in aquatic medium with different water hardness (Grosell, Nielsen, & Bianchini, 2002; Monteiro, Mancera, Fontainhas-Fernandes, & Sousa, 2005; Atli & Canli 2011; Saglam et al., 2013). Acetylcholinesterase (AChE, EC 3.1.1.7) functioning in the neurotransmitter acetylcholine hydrolysis is important component of the neuronal communication. AChE is known to be abundant for brain tissue and therefore AChE response can be used for the xenobiotic diagnosing particularly for neurotoxicity determining in the aquatic environment (Üner, Sevgiler, & Piner, 2010; Richetti et al. 2011; Silva, Assis, Oliveira, Carvalho, & Bezerra, 2013). In addition, metals are also effective since they cause significant changes in AChE activities in fish as indicated in the literature (Romani et al., 2003; Jebali et al., 2006; Attig et al., 2010). There are more detailed knowledge of the acute toxic mechanisms of several waterborne trace metals such as silver, cadmium and copper than nickel (Brix et al., 2017).

It has gain significance to highlight the  $\text{Ca}^{2+}$  effect on metal toxicity consequences on osmoregulatory responses and neurotoxicity in fish. In this purpose, the main objective of current study was to evaluate the alteration in ATPase and AChE activities in the means of osmo- and neuroregulatory effects of  $\text{Hg}^{2+}$  and  $\text{Ni}^{2+}$  in different  $\text{Ca}^{2+}$  levels in the brain of Nile tilapia, *O. niloticus*.

## Materials and Methods

One year old *O. niloticus* (Perciformes: Cichlidae) were obtained from fish culturing pools of Çukurova University and transferred to the laboratory, where they were acclimatized ( $20\pm 1^\circ\text{C}$ ) and illuminated for 12 h with fluorescent lamps (daylight 65/80 W) for one

month. The experiments were carried out in glass aquariums sized 40x40x100 cm that contained 120 L Nestle water (Nestle Pure Life, Turkey). All experiments were conducted by the Nestle Water containing relatively low  $\text{Ca}^{2+}$  levels (15 mg  $\text{Ca}^{2+}$ /L) and used as normal (base) control. The aquaria were aerated with air stones attached to an air compressor to saturate with oxygen ( $7.03\pm 0.81$  mg  $\text{O}_2$ /L). The pH, conductivity, total hardness and alkalinity levels of the Nestle water were  $6.83\pm 0.01$ ,  $77 \mu\text{S}/\text{cm}$ ,  $105.4\pm 20.8$  mg  $\text{CaCO}_3/\text{L}$  and  $76.2\pm 13.0$  mg  $\text{CaCO}_3/\text{L}$ , respectively. No contamination in this water was stated based on the Nestle quality control document (Nestle, Turkey). Fish size and weight were measured as  $15.4\pm 1.33$  cm and  $57.5\pm 16.4$  g, respectively and they did not differ significantly ( $P>0.05$ ) among different exposure groups.

For the experimental design, control-Ca and metal+Ca groups were used for acute (3 d) and chronic (30 d) durations. A total of six fish were used for each experimental group. Control-Ca groups had different  $\text{Ca}^{2+}$  levels as 15 (low), 30 (medium) and 90 mg  $\text{Ca}^{2+}$ /L (high), respectively. Calcium levels of this water were increased by adding  $\text{CaCl}_2\cdot 2\text{H}_2\text{O}$ . Calgon Titration Method was used to measure the exposure media  $\text{Ca}^{2+}$  levels and they were found within 5% of the nominal target  $\text{Ca}^{2+}$  levels. Total hardness levels of the  $\text{Ca}^{2+}$  groups were found as  $105.4\pm 20.8$  (L-Ca),  $194.0\pm 12.3$  (M-Ca) and  $318.0\pm 13.0$  mg  $\text{CaCO}_3/\text{L}$  (H-Ca), respectively. The pH values were in the range of  $6.83\text{--}6.73\pm 0.01$  in the groups. Metal+Ca groups were exposed to  $\text{Hg}^{2+}$  ( $\text{HgCl}_2$ ) and  $\text{Ni}^{2+}$  ( $\text{NiCl}_2\cdot 6\text{H}_2\text{O}$ ) at three  $\text{Ca}^{2+}$  media (low, medium and high). Acute (0.3  $\mu\text{M}$ ) and chronic (0.03  $\mu\text{M}$ )  $\text{Hg}^{2+}$  exposed groups were mentioned as Hg+L-Ca, Hg+M-Ca and Hg+H-Ca, respectively. Acute (30  $\mu\text{M}$ ) and chronic (10  $\mu\text{M}$ )  $\text{Ni}^{2+}$  exposed groups were mentioned as Ni+L-Ca, Ni+M-Ca and Ni+H-Ca, respectively (Table 1). Fish were fed (2% of their weight) with Pinar Sazan commercial fish food (Izmir, Turkey). The aquaria of experimental groups were cleaned every 2 days after the feeding to eliminate the food remains and also to minimize metal loss in the medium (Atli & Canli, 2007).

At the end of the exposure durations, fish were killed by transaction of the spinal cord based on the Çukurova University Ethic Committee decision. Brain tissues were dissected out with sterile equipment and stored (Revco Ultima II, Newsbreak, UK) at  $-80^\circ\text{C}$  until the analysis.

## Enzyme Analysis

Tissues were homogenized in ice-cold buffer (20 mM Tris-HCl, 0.25 M Sucrose and 1 mM EDTA, pH 7.7) with a ratio of 1/10 (v/w) at 9500 rpm for 1-2 min. Homogenates were centrifuged at 13 000 g for 20 min ( $4^\circ\text{C}$ ). The supernatants were used for enzymatic activity and protein level measurements.

ATPase activity measurement was performed by

using the incubation media (pH 7.7) contained 40 mM Tris-HCl, 120 mM NaCl, 20 mM KCl, 3 mM MgCl<sub>2</sub>, and 1 mM for ouabain. The reaction was started by the addition of 3 mM Na<sub>2</sub>ATP as a substrate and incubated for 30 min at 37°C. Inorganic phosphate measurement at 390 nm was used for the ATPase activity determination (Atkinson, Gatemby, & Lowe, 1973). KH<sub>2</sub>PO<sub>4</sub> was used as a standard. Na<sup>+</sup>/K<sup>+</sup>-ATPase activity was calculated by using the activity differences between the presence (Mg<sup>2+</sup>-ATPase activity) and absence (Total-ATPase activity) of the ouabain. ATPase activities were calculated as μmol Pi/mg prot./min. The characterization of the ATPase activities in *O. niloticus* was presented in our laboratory previously (Atli & Canli, 2011).

AChE specific activity was measured according to Ellman, Courtney, Andres and Featherstone (1961) based on the absorbance increase at 412 nm for 1 min. The incubation media contained 0.1 M sodium-phosphate buffer (pH 8.0), 0.01 M DTNB and 8.52 mM ethopropazine (BChE inhibitor). Reaction was started by 0.015 M acetylthiocholine (substrate) addition. AChE activity was calculated as U/mg prot. by using an extinction coefficient 13.6 mM<sup>-1</sup> cm<sup>-1</sup>. Total protein levels were determined based on the method of Lowry, Rosebrough, Farra and Randall (1951) and bovine serum albumin used as a standard. Assays were performed in triplicate. All chemicals were obtained from Sigma (Germany) or Merck (Germany).

## Statistics

Statistical analysis were performed by using SPSS statistical package program (SPSS 13, Chicago, IL, USA) and given as mean and standard error (N = 6). Kolmogorov-Smirnov normality test was used to control the homogeneity of variance among different exposure groups. One-way ANOVA followed by Duncans' test and T-test (P< 0.05) was used to compare the groups individually in acute and chronic exposures. In addition the control-Ca groups (L-, M- and H-Ca groups) and metal-Ca<sup>2+</sup> groups were compared individually for determination of the Ca<sup>2+</sup> effect alone and Ca<sup>2+</sup> effect on metal toxicity, respectively.

## Results

In acute exposure, there were no alteration in the enzyme activities of the control groups in differing Ca<sup>2+</sup> concentrations except Mg<sup>2+</sup>-ATPase activities which increased in H-Ca group in contrast to L-Ca group (P<0.05). The trend of the changes were observed as decreases in metal exposed groups summarized in Table 2. Total-ATPase activities were decreased in M-Ca and H-Ca groups with Ca concentration dependent in contrast to L-Ca groups after acute Hg<sup>2+</sup> and Ni<sup>2+</sup> exposures. When comparing with their own Ca concentrations; Total-ATPase activities increased in L-Ca groups though they decreased in H-Ca groups after

**Table 1.** The scheme of the experimental group design in differing Ca<sup>2+</sup> concentrations for acute and chronic duration

	Acute (3 days)			Chronic (30 days)		
	Control	Hg	Ni	Control	Hg	Ni
Low-Ca (15 mg Ca <sup>2+</sup> /L)	L-Ca	0.3 μM Hg+L-Ca	30 μM Ni+L-Ca	L-Ca	0.03 μM Hg+L-Ca	10 μM Ni+L-Ca
Medium-Ca (30 mg Ca <sup>2+</sup> /L)	M-Ca	0.3 μM Hg+M-Ca	30 μM Ni+M-Ca	M-Ca	0.03 μM Hg+M-Ca	10 μM Ni+M-Ca
High-Ca (90 mg Ca <sup>2+</sup> /L)	H-Ca	0.3 μM Hg+H-Ca	30 μM Ni+H-Ca	H-Ca	0.03 μM Hg+H-Ca	10 μM Ni+H-Ca

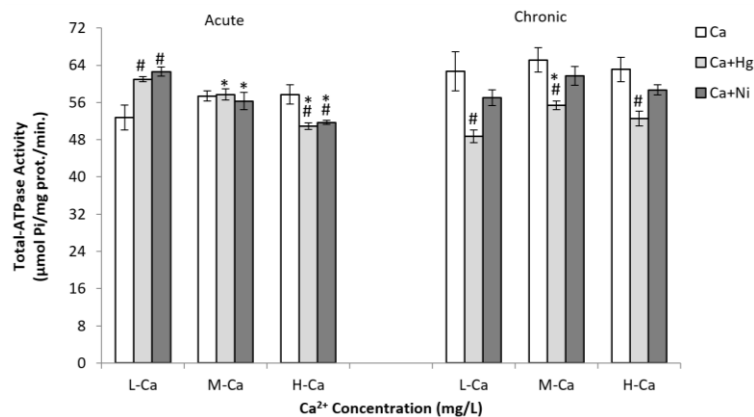
**Table 2.** A summary of significant changes (P<0.05) of ATPase and AChE activities in the brain of *O. niloticus* exposed to acute mercury and nickel exposures in differing Ca<sup>2+</sup> concentrations. Significant increases and decreases (P<0.05) were represented as “↑” and “↓”, respectively while “-” indicated the insignificant data (P>0.05)

Enzyme	Group	Acute					
		In contrast to L-Ca group			In contrast to own Ca alone media		
		L-Ca	M-Ca	H-Ca	L-Ca	M-Ca	H-Ca
Total-ATPase	Control	52.8±2.69	57.4±1.08	57.7±2.07			
	Hg	61.0±0.54	57.7±1.19 ↓	50.9±0.75 ↓	↑	-	↓
	Ni	62.6±0.98	56.3±1.88 ↓	51.7±0.43 ↓	↑	-	↓
Mg <sup>2+</sup> -ATPase	Control	28.1±1.94	32.0±0.77	34.0±2.07 ↑			
	Hg	33.1±0.92	31.4±0.94	28.8±0.75 ↓	↑	-	↓
	Ni	42.7±0.92	39.5±1.30	34.5±0.43 ↓	↑	↑	-
Na <sup>+</sup> /K <sup>+</sup> -ATPase	Control	22.3±1.50	24.5±1.07	24.9±0.89			
	Hg	26.4±0.98	23.3±0.53 ↓	22.8±0.88 ↓	↑	-	-
	Ni	19.9±0.66	15.9±0.86 ↓	17.1±0.52 ↓	-	↓	↓
AChE	Control	0.083±0.003	0.081±0.004	0.076±0.001			
	Hg	0.090±0.002	0.074±0.004 ↓	0.087±0.006	↑	-	↑
	Ni	0.077±0.002	0.071±0.004	0.068±0.001	-	-	-

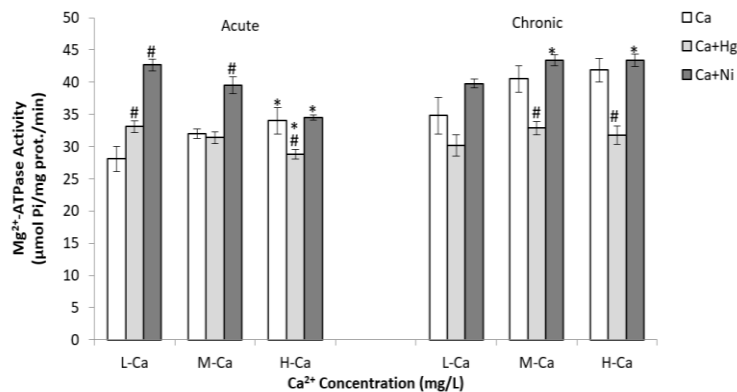
both metal exposures ( $P < 0.05$ ) (Figure 1).  $Mg^{2+}$ -ATPase activities decreased in Hg+H-Ca and Ni+H-Ca groups compared to Hg+L-Ca and Ni+L-Ca groups, respectively.  $Mg^{2+}$ -ATPase activities increased in Hg+L-Ca, Ni+L-Ca and Ni+M-Ca groups though decreased in Hg+H-Ca group in contrast to their alone own  $Ca^{2+}$  environments ( $P < 0.05$ ) (Figure 2).  $Na^+/K^+$ -ATPase activity decreased after both acute  $Hg^{2+}$  and  $Ni^{2+}$  exposures in M-Ca and H-Ca groups when compared to Hg and Ni+L-Ca groups, respectively.  $Na^+/K^+$ -ATPase activity increased in Hg+L-Ca group though Ni+M-Ca and Ni+H-Ca group activities decreased in contrast to their own  $Ca^{2+}$  concentrations ( $P < 0.05$ ) (Figure 3). AChE activity during acute durations decreased in Hg+M-Ca group in contrast to Hg+L-Ca group. Increases were found in AChE activity in L- and H-Ca groups after Hg exposures when compared to their own alone  $Ca^{2+}$  media ( $P < 0.05$ ) (Figure 4).

In chronic exposure, the ATPase and AChE activities did not change among the studied  $Ca^{2+}$  concentrations in control groups ( $P > 0.05$ ). The altered

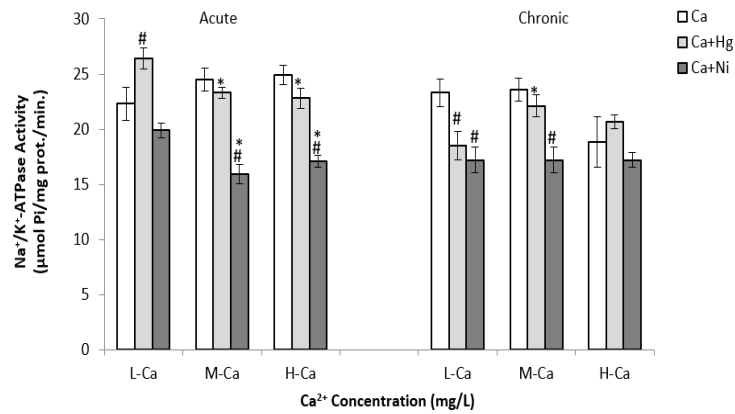
activities were found lower in this duration than acute exposure groups and both increases and decreases were observed after metal exposures in differing  $Ca^{2+}$  conditions (Table 3). Total-ATPase activity increased after Hg+M-Ca exposure in contrast to Hg+L-Ca group. All activities of Total-ATPase decreased after  $Hg^{2+}$  exposure in all  $Ca^{2+}$  environments when comparing to their own control  $Ca^{2+}$  concentrations ( $P < 0.05$ ) (Fig. 1).  $Mg^{2+}$ -ATPase activity increases were recorded in Ni+M-Ca and Ni+H-Ca groups in contrast to Ni+L-Ca group. However its activity decreased after Hg+M-Ca and Hg+H-Ca exposures when compared to M-Ca and H-Ca exposures ( $P < 0.05$ ) (Figure 2).  $Na^+/K^+$ -ATPase activity increased only in Hg+M-Ca compared to Hg+L-Ca group. Its activity decreased after Hg+L-Ca, Ni+L-Ca and Ni+M-Ca exposures in contrast to their own  $Ca^{2+}$  environments ( $P < 0.05$ ) (Figure 3). AChE activity decreased only in L-Ca groups after  $Hg^{2+}$  and  $Ni^{2+}$  exposures compared to their own  $Ca^{2+}$  alone environment ( $P < 0.05$ ) (Figure 4).



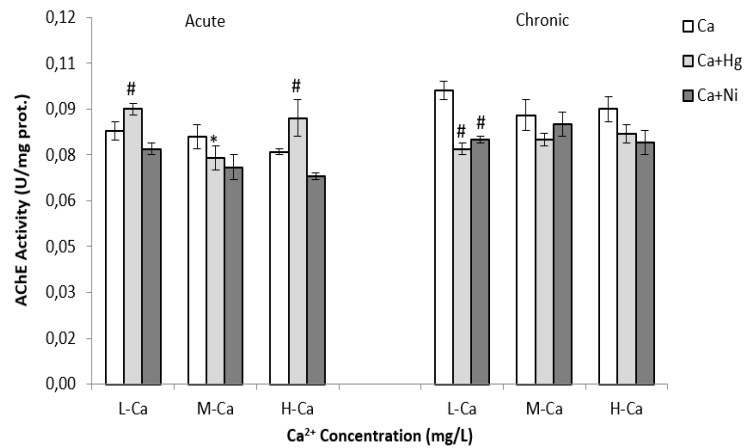
**Figure 1.** Total-ATPase activities in the brain of *O. niloticus* exposed to acute and chronic  $Hg^{2+}$  and  $Ni^{2+}$  in differing  $Ca^{2+}$  concentrations. Data ( $N=6$ ) are given as mean  $\pm$  standard error. Statistical significances ( $P < 0.05$ ) were indicated as “\*” between L-Ca group and M-Ca ( $30 \text{ mg } Ca^{2+}/L$ ) and H-Ca ( $90 \text{ mg } Ca^{2+}/L$ ) groups, while “#” was used to indicate the significant ( $P < 0.05$ ) changes between metal+Ca groups (Metal+L-Ca, Metal+M-Ca and Metal+H-Ca) and their own control-Ca groups (L-Ca, M-Ca and H-Ca).



**Figure 2.**  $Mg^{2+}$ -ATPase activities in the brain of *O. niloticus* exposed to acute and chronic  $Hg^{2+}$  and  $Ni^{2+}$  in differing  $Ca^{2+}$  concentrations. See Figure 1 for details.



**Figure 3.**  $\text{Na}^+/\text{K}^+$ -ATPase activities in the brain of *O. niloticus* exposed to acute and chronic  $\text{Hg}^{2+}$  and  $\text{Ni}^{2+}$  in differing  $\text{Ca}^{2+}$  concentrations. See Figure 1 for details.



**Figure 4.** AChE activities in the brain of *O. niloticus* exposed to acute and chronic  $\text{Hg}^{2+}$  and  $\text{Ni}^{2+}$  in differing  $\text{Ca}^{2+}$  concentrations. See Figure 1 for details.

**Table 3.** A summary of significant changes ( $P < 0.05$ ) of ATPase and AChE activities in the brain of *O. niloticus* exposed to chronic mercury and nickel exposures in differing  $\text{Ca}^{2+}$  concentrations. Significant increases and decreases ( $P < 0.05$ ) were represented as “ $\uparrow$ ” and “ $\downarrow$ ”, respectively while “-” indicated the insignificant data ( $P > 0.05$ )

Enzyme	Group	Chronic					
		In contrast to L-Ca group			In contrast to own Ca alone media		
		L-Ca	M-Ca	H-Ca	L-Ca	M-Ca	H-Ca
Total-ATPase	Control	62.7 $\pm$ 4.23	65.1 $\pm$ 2.62	63.1 $\pm$ 2.64			
	Hg	48.7 $\pm$ 1.37	55.4 $\pm$ 0.90 $\uparrow$	52.5 $\pm$ 1.59	$\downarrow$	$\downarrow$	$\downarrow$
	Ni	57.0 $\pm$ 1.70	61.7 $\pm$ 2.05	58.7 $\pm$ 1.11	-	-	-
$\text{Mg}^{2+}$ -ATPase	Control	34.8 $\pm$ 2.87	40.5 $\pm$ 2.05	41.9 $\pm$ 1.81			
	Hg	30.2 $\pm$ 1.62	32.9 $\pm$ 1.01	31.8 $\pm$ 1.42	-	$\downarrow$	$\downarrow$
	Ni	39.8 $\pm$ 0.66	43.4 $\pm$ 0.80 $\uparrow$	43.4 $\pm$ 0.99 $\uparrow$	-	-	-
$\text{Na}^+/\text{K}^+$ -ATPase	Control	23.3 $\pm$ 1.28	23.6 $\pm$ 1.02	18.8 $\pm$ 2.29			
	Hg	18.5 $\pm$ 1.32	22.1 $\pm$ 1.00 $\uparrow$	20.7 $\pm$ 0.62	$\downarrow$	-	-
	Ni	17.2 $\pm$ 1.16	17.2 $\pm$ 1.14	17.2 $\pm$ 0.68	$\downarrow$	$\downarrow$	-
AChE	Control	0.096 $\pm$ 0.003	0.077 $\pm$ 0.002	0.080 $\pm$ 0.001			
	Hg	0.077 $\pm$ 0.002	0.080 $\pm$ 0.002	0.082 $\pm$ 0.003	$\downarrow$	-	-
	Ni	0.080 $\pm$ 0.001	0.085 $\pm$ 0.004	0.079 $\pm$ 0.004	$\downarrow$	-	-

## Discussion

Data showed variable responses of ATPase and AChE activities dependent upon the metal species, their concentrations and durations in different  $\text{Ca}^{2+}$  media. In addition unchanged enzyme activities were also recorded mostly in control groups with different  $\text{Ca}^{2+}$  media (Table 2 and 3). It is interesting to observe the decreased enzyme activities upon acute metal exposures even at high  $\text{Ca}^{2+}$  concentration for several cases. However, they became to return to their control values after chronic exposure at high  $\text{Ca}^{2+}$  media. According to this, acute and chronic exposures seemed to be differed in the opposite way from a whole point of view based on the activity responses also associated with metal concentration differences. Metal effects were still observed, particularly at L-Ca group in contrast to their  $\text{Ca}^{2+}$  alone group.

### ATPase Activities

ATPase activities were more affected in acute exposure than chronic duration and this could be also related with higher concentrations of mercury and nickel. One can conclude that  $\text{Ca}^{2+}$  increase might cause a reduction in metal toxicity due to the less alteration in the activities when compared to their same  $\text{Ca}^{2+}$  environment during chronic exposure period. It could be occurred in a linked with  $\text{Ca}^{2+}$  protection by decreasing the metal bioavailability. In general, after acute duration, ATPase activities decreased at higher  $\text{Ca}^{2+}$  media according to both L-Ca group and own  $\text{Ca}^{2+}$  alone media comparisons. However they mostly increased after metal exposures in contrast to their own  $\text{Ca}^{2+}$  media. Nevertheless in chronic duration, less affected ATPase activity trend was as decreases in contrast to own  $\text{Ca}^{2+}$  group. Metals, particularly  $\text{Hg}^{2+}$  significantly decreased the ATPase activities when compared to their own  $\text{Ca}^{2+}$  media due to its high toxicity. Data presented its activity change as mostly in decreases could be in relation to disruption of ion concentrations after  $\text{Hg}^{2+}$  and  $\text{Ni}^{2+}$  exposures at different  $\text{Ca}^{2+}$  environment. This decrease could be also associated with metal binding directly to the enzyme structure leading to a dysfunction in its activity (Dogan, Atli, & Canli, 2015). However different pattern was observed in  $\text{Mg}^{2+}$ -ATPase activity as both increases and decreases in relation to metal and  $\text{Ca}^{2+}$  concentration differences. Its role is known to transport the  $\text{Mg}^{2+}$  which is essential for the cellular membrane integrity and permeability. The increases could be associated with the increased ion concentrations and other compensation mechanisms acting to maintain the fish metabolism under stress.

It was obvious that both  $\text{Ca}^{2+}$  and also metal ( $\text{Hg}^{2+}$  and  $\text{Ni}^{2+}$ ) effects disturbance the ATPase activity as a result of imbalanced ion-based osmoregulation. One of the most effective factors,  $\text{Ca}^{2+}$  can compete with

metal ions for uptake in freshwater organisms is known to be able to reduce the metal bioavailability and toxicity consequently (Heath, 1995). Inverse relationship was observed between toxicity of metals and water hardness as  $\text{Ca}^{2+}$  ions in *O. niloticus* (Hollis, McGeer, McDonald, & Wood, 2000; Franklin, Glover, Nicol, & Wood, 2005; Saglam et al., 2013). Nevertheless,  $\text{Ca}^{2+}$  protection was appeared to be occurred particularly at chronic duration when compared to acute period. This could be linked with the high metal concentrations used for acute exposure. On this basis, it can be concluded that protective role of the  $\text{Ca}^{2+}$  can be varied/alterd according to the other criteria such as metal concentration and exposure duration which was also supported with this and ours previous studies (Canli, Atli, & Canli, 2016). Our previous data also emphasized the variable ATPase responses depending upon the metal type, concentration, exposure duration, tissue differences and also physicochemical properties of aquatic environment (Atli & Canli, 2007; Atli & Canli, 2011; Saglam et al., 2013). In addition ion concentrations in both tissues and the fish serum significantly altered by metal exposures after acute and chronic durations (Oner et al., 2008; Atli & Canli, 2011; Saglam et al., 2013). Enhanced ATPase activities might be occurred by increased enzyme turnover rates and/or enzyme molecule numbers. In addition to this, possible changes in the levels of ions which are essential in membrane stability and permeability, followed by osmotic gradient changes may also cause alterations in ATPase activities.

Inhibition in brain  $\text{Na}^+/\text{K}^+$ -ATPase activity after  $\text{Hg}^{2+}$  exposure were also demonstrated in its ability to interfere with metal binding sites on ATPase molecule which may lead to an alteration in enzyme configuration (Verma, Jain, & Tonk, 1983; Sastry & Sharma, 1980; Omotayo, Rocha, Ibukun, & Kade, 2011). Reduced effect of  $\text{Ag}^+$  exposure due to increased water hardness was observed in ion levels and  $\text{Na}^+/\text{K}^+$ -ATPase activity in the gill of rainbow trout (Morgan, Guadagnolo, Grosell, & Wood, 2005). Although lower sensitivity of  $\text{Mg}^{2+}$ -ATPase than  $\text{Na}^+/\text{K}^+$ -ATPase activity found in some of our earlier data (Atli & Canli, 2011; 2013) against metal toxicity, they showed equivalent responses in the present study. This different endpoint might be explained by tissue differences. The brain utilizing approximately 20% total oxygen demand of the metabolism has a vital role in neuro-endocrine functions. Also it can be very sensitive to oxidative damage due to containing high amounts of unsaturated lipids. Decreased  $\text{Na}^+/\text{K}^+$ -ATPase activity with altered antioxidant enzyme activities in fish exposed to metals were observed (Atli & Canli, 2007; Maiti, Saha, & Paul, 2010). Increased ATPase activity in order to supply the energy demand was also supported by previous data (Sastry & Sharma, 1980; Saglam et al., 2013). In addition, this study pointed out that the duration effect

belonging to the different metal concentrations was not the only factor lead to activity changes. Calcium was also found as a significant component responsible for these variations.

### AChE Activity

AChE activity showed both increases and decreases based on the metal, concentration, duration and the  $\text{Ca}^{2+}$  media. Significant alterations in AChE activities were observed in acute duration as variations after only  $\text{Hg}^{2+}$  exposure. In chronic duration as decreases in low  $\text{Ca}^{2+}$  conditions were found after both metal exposures in contrast to their own  $\text{Ca}^{2+}$  concentrations. Alterations in AChE activity by  $\text{Hg}^{2+}$  exposure could point out its anticholinergic effect. AChE represented minor changes compared to ATPase activities in the current data. This may be related to the fact that the enzyme is less sensitive to these metals than ATPase responses. Brain tissue is endowed with AChE that functions in acetylcholine hydrolyze into choline and acetic acid at the cholinergic synapses. The AChE increases at different  $\text{Ca}^{2+}$  media after  $\text{Hg}^{2+}$  exposure in acute duration could be linked with de novo synthesis of the enzyme. There were several studies demonstrating the increased AChE activity after metal exposures despite AChE activity decreases shown literature in general. Increased brain AChE activities were demonstrated in several fish species after metal exposures (Gill, Tewari, & Pande, 1991; Romani et al., 2003; Jebali et al., 2006). Variability of AChE activity responses against metal toxicity dependent with the duration differences in several aquatic organisms were also recorded in the literature (Aziz, Amin, & Shakoori, 1993; Reddy & Venugopal, 1993; Attig et al., 2010). On the other hand one of the major roles of  $\text{Ca}^{2+}$  is to act as a significant intracellular second messenger of central nervous system and  $\text{Ca}^{2+}$  has been also found to involve in the release of neurotransmitter (Reddy, Jinna, Uzodinma, & Desaiyah, 1988). Based on this information, there is a question of whether the increase in AChE activity is caused by also this role of calcium in relation with the different  $\text{Ca}^{2+}$  concentrations used in this study.

On the other hand, decreased AChE activity pattern showed similarity with the  $\text{Na}^+/\text{K}^+$ -ATPase activity. Possible reasons of the AChE activity decline might be associated with metal binding to the enzyme structure leading to compromised catalytic activity and/or increased lipid peroxidation which can indirectly effects its activity (Pretto et al., 2014). Acetylcholine accumulation can be occurred due to the AChE inhibition which in turn can impact the physiological mechanisms such as swimming, behavioral and survival of fish as a result of prevention of nerve and muscle fiber communication (Uner et al., 2010; Katuli, Massarsky, Hadadi, & Pourmehrhan, 2014). Decreased

brain AChE activity after  $\text{Ni}^{2+}$  treatment for 21 days in rainbow trout (Topal et al., 2015) showed similarity with this study only after chronic  $\text{Ni}^{2+}$  exposure at low  $\text{Ca}^{2+}$  media. In addition there were no alterations in its activity at higher  $\text{Ca}^{2+}$  concentrations. This result might be related with  $\text{Ca}^{2+}$  protection against metal toxicity in chronic duration. Inhibitions were demonstrated in fish *Pomatoschistus microps* (Vieira, Gravato, Soares, Morgado, & Guilhermino, 2009) and *Danio reiro* (Zhen et al., 2014) AChE activities against acute mercury exposures. De la Torre, Salibian, and Ferrari (2000) demonstrated unaltered brain AChE activity, inhibition in  $\text{Na}^+/\text{K}^+$ -ATPase and activation in  $\text{Mg}^{2+}$ -ATPase activities in the gill of *Cyprinus carpio* exposed to  $\text{Cd}^{2+}$  and they commented that AChE was seemed to be not a suitable marker in relation to  $\text{Cd}^{2+}$  toxicity.  $\text{Na}^+/\text{K}^+$ -ATPase and AChE activities inhibited in different fish species exposed to metals as a result of metal interference with iono- and neuro-regulation underlying their usage as an early biomarker concept in contaminated waters (Katuli et al., 2014; Leitemperger et al., 2016).

As a result it can be concluded that both osmo- and neuro-regulation were affected by metal exposures in different concentrations and durations with increased  $\text{Ca}^{2+}$  media. It is interesting to observe the decreased enzyme activities after acute metal exposures even at high  $\text{Ca}^{2+}$  concentration. And also higher metal effects were remarkable at low  $\text{Ca}^{2+}$  groups in both durations in contrast to their control group. Therefore AChE and ATPase activity changes should be taken into account while evaluating the toxicity response of the brain. However, osmotic and ionic disruption can be pronounced as higher in the means of ATPase activity changes than AChE activity in tilapia after metal stress. Nevertheless, to measure the multiple biomarker responses simultaneously has gain significance for showing correspondence to aquatic stress conditions. Therefore approach of specific and sensitive multi-biomarker usage and also validity of different biomarker integration are seemed to be essential to evaluate the osmo- and neuro-toxicity mechanisms under metal stress with different  $\text{Ca}^{2+}$  levels.

### Acknowledgement

This study was supported by a Çukurova University Fund (FBA-2014-2592).

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