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”المستجدات الحديثة في التعليم العالي في ظل التعليم الالكتروني“

17-16 كانون الاول 2020 (المجلد الخامس)



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## On the convergence of three – Step – One Mapping Iterative Scheme in $W$ -Hyperbolic Space

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### Abstract

In this paper , firstly we introduce A Three – Step – One Mapping Iterative scheme for self mapping in  $W$ -Hyperbolic space secondly we prove a convergence result of A Three – Step – One Mapping Iterative Scheme for Nonexpansive mapping in the same space also established the convergence results when use Condition  $(I)$  and by using Hemicompact mapping in uniformly  $W$ -Hyperbolic space.

### Key Words

A Three – Step – One Mapping Iterative Scheme in , Nonexpansive mapping , uniformly Hyperbolic Space , Condition  $(I)$  .



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## 1 – Introduction

In 2009 , Shahzad and Zegeye [1] introduced the convergence result of Ishikawa iteration for quasi nonexpansive multivalued maps in uniformly convex space as follows , for any  $x_1 \in B$

$$x_{n+1} = (1 - \tau_n)x_n + \tau_n \ell_n$$

$$y_n = (1 - \mu_n)x_n + \mu_n t_n ; \forall n \geq 0$$

Where  $\ell_n \in Ly_n , t_n \in Lx_n , \{\mu_n\}$  and  $\{\tau_n\}$  are sequences in  $[0,1]$ .

In 2010, Khan et al . [2] introduced weak and strong convergence result of a one step iteration for two multivalued nonexpansive mappings .

Also in 2011, Abbas et al . [3] established the convergence result of a new one step iteration for two multivalued nonexpansive mappings in uniformly convex Banach space as follows , for any  $x_1 \in B$

$$x_{n+1} = \mu_n x_n + \tau_n t_n + \sigma_n \ell_n ; \forall n \geq 0$$

Where  $\ell_n \in Lx_n , t_n \in Kx_n , \{\mu_n\} , \{\tau_n\}$  and  $\{\sigma_n\}$  are sequences in  $(0,1)$ . In 2018, Birol G .and Sezgin A. [4] established the convergence result of a one step iteration for two multivalued nonexpansive mappings in uniformly convex W- Hyperbolic space as follows , for any  $x_1 \in B$

$$x_{n+1} = W(\ell_n , W(x_n , t_n , \frac{\tau_n}{1 - \mu_n}) , \mu_n) ; \forall n \geq 0$$

Where  $\ell_n \in Lx_n , t_n \in Kx_n , \{\mu_n\}$  and  $\{\tau_n\}$  are sequences in  $(0,1)$ .



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## 2 –Preliminaries

Definition (2.1)[5] : A metric space  $(E, d)$  is said to be hyperbolic space if there exist a map  $W: E^2 \times [0,1] \rightarrow E$  satisfying :

$$W1 - d(t, W(x, y, \mu)) \leq (1 - \mu)d(t, x) + \mu d(t, y)$$

$$W2 - d(W(x, y, \mu), W(x, y, \delta)) = |\mu - \delta| d(x - y)$$

$$W3 - W(x, y, \mu) = W(y, x, (1 - \mu))$$

$$W4 - d(W(x, c, \mu), W(y, e, \mu)) \leq (1 - \mu)d(x, y) + \mu d(c, e)$$

$$\forall x, y, c, e \in E \text{ and } \mu, \delta \in [0,1].$$

Definition (2.2)[6]: Let  $A$  be a non-empty and convex subset of a hyperbolic space  $B$ . A mapping  $L: A \rightarrow A$  is said to be

$$(i) \text{ nonexpansive if } d(Lx, Ly) \leq d(x, y) \quad \dots (1)$$

$$\forall x, y \in A.$$

$$(ii) \text{ quasi nonexpansive if } F(L) \neq \emptyset \text{ and } d(Lx, \rho) \leq d(x, \rho) \quad \dots (2)$$

$$\forall x \in A \text{ and } \rho \in F(L).$$

Definition (2.3) : Let  $A$  be a non-empty and convex subset of a hyperbolic space  $B$  and  $L: A \rightarrow A$  is a mapping for any  $x_1 \in A$ , the sequence  $\{x_n\}$  define by

$$x_{n+1} = W(Ly_n)$$

$$y_n = W(Lx_n, Lz_n, \mu_n)$$

$$z_n = W(x_n, Lx_n, \tau_n); \forall n \geq 0 \quad \dots (3)$$



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where  $\{\mu_n\}$  and  $\{\tau_n\}$  are sequences in  $(0,1)$ .

Definition (2.4) [7]: A hyperbolic space  $(E, d, W)$  is said to be uniformly convex if  $\exists \sigma \in ]0,1]$  such that

$d(x, \vartheta) \leq \gamma, d(y, \vartheta) \leq \gamma$  and  $d(x, y) \geq \epsilon\gamma$  then

$$d\left(W\left(x, y, \frac{1}{2}\right), \vartheta\right) \leq (1 - \sigma)\gamma$$

$\forall \vartheta, x, y \in E, \epsilon \in (0,2]$  and  $\gamma > 0$

Lemma(2.5 ), [8] : Let  $B$  be a uniformly convex hyperbolic . Let  $x \in B$  and  $\{\mu_n\}$  be a sequence in  $[g, h]$  for some  $g, h \in (0,1)$ . If  $\{x_n\}$  and  $\{y_n\}$  are sequences in  $B$  such that

$\lim_{n \rightarrow \infty} \text{supd}(x_n, x) \leq \varphi, \lim_{n \rightarrow \infty} \text{supd}(y_n, x) \leq \varphi$  and  
 $\lim_{n \rightarrow \infty} d(W(x_n, y_n, \mu_n), x) = \varphi$  for some  $\varphi \geq 0$

then  $\lim_{n \rightarrow \infty} d(x_n, y_n) = 0$ .

Definition (2.6)[9] : Let  $A$  be a non-empty and convex subset of a hyperbolic space  $B$ . A mapping  $L: A \rightarrow A$  is said to be

(i) Satisfy condition (I) if  $\exists$  a nondecreasing function  $k: [0, \infty[ \rightarrow [0, \infty[$  with  $k(0) = 0, k(\alpha) > 0$  for  $\alpha \in (0, \infty)$  such that

$$d(x, Lx) \geq k(d(x, F(L))), \forall x \in A.$$

(ii) Hemicompact. If for any sequence  $\{x_n\}$  in  $A \ni \lim_{n \rightarrow \infty} d(x_n, Lx_n) = 0,$

$\exists$  a subsequence  $\{x_{n_t}\}$  of  $\{x_n\}$  such that  $x_{n_t} \rightarrow \rho$  as  $t \rightarrow \infty$  for some

$\rho \in A.$

### 3 – Main Theorem



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### Theorem(3.1):

Let  $B$  is a hyperbolic space ,  $A$  is a nonempty and convex subset of  $B$  and  $L: A \rightarrow A$  is a quasi nonexpansive mapping . Let  $\{x_n\}$  define by condition (3) with  $\mu_n$  and  $\tau_n \in (0,1)$ . If  $\rho \in F(L)$ ,

then  $\lim_{n \rightarrow \infty} d(x_n, \rho)$  exists ,  $\forall \rho \in F(L)$ .

Proof: Let  $\rho \in F(L)$ , from condition (2) and(3) , we get

$$\begin{aligned} d(z_n, \rho) &= d(W(x_n, Lx_n, \tau_n), \rho) \\ &\leq (1 - \tau_n)d(x_n, \rho) + \tau_n d(Lx_n, \rho) \\ &\leq (1 - \tau_n)d(x_n, \rho) + \tau_n d(x_n, \rho) \\ &= d(x_n, \rho) \end{aligned} \dots (4)$$

From condition (2) , (3) and (4) , we get

$$\begin{aligned} d(y_n, \rho) &= d(W(Lx_n, Lz_n, \mu_n), \rho) \\ &\leq (1 - \mu_n)d(Lx_n, \rho) + \mu_n d(Lz_n, \rho) \\ &\leq (1 - \mu_n)d(x_n, \rho) + \mu_n d(z_n, \rho) \\ &\leq (1 - \mu_n)d(x_n, \rho) + \mu_n d(x_n, \rho) \\ &= d(x_n, \rho) \end{aligned} \dots (5)$$

From condition (2) , (3)(4), and (5) , we get

$$\begin{aligned} d(x_{n+1}, \rho) &= d(W(Ly_n), \rho) \\ &\leq d(Ly_n, \rho) \\ &\leq d(y_n, \rho) \\ &\leq d(x_n, \rho) \end{aligned} \dots (6)$$



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Then  $\{d(x_n, \rho)\}$  is bounded and non- increasing . Hence  $\lim_{n \rightarrow \infty} d(x_n, \rho)$  exists ,  $\forall \rho \in F(L)$ .

**Theorem(3.2):**

Let  $B, A, L$  and  $\{x_n\}$  be as in theorem(3.1), where  $\mu_n$  and  $\tau_n$  are sequences in  $[g, h]$  for some  $g, h$  with  $0 < a \leq b < 1$ . Then  $F(L) \neq \emptyset$  if and only if  $\{x_n\}$  is bounded and  $\lim_{n \rightarrow \infty} d(Lx_n, x_n) = 0$ .

Proof: Suppose  $F(L) \neq \emptyset$  and Let  $\rho \in F(L)$ , then  $\lim_{n \rightarrow \infty} d(x_n, \rho)$  exists and  $\{x_n\}$  is bounded .Put

$$\lim_{n \rightarrow \infty} d(x_n, \rho) = \varphi. \text{ for some } \varphi > 0 \quad \dots (7)$$

From condition (4) and (7), we get

$$\begin{aligned} \limsup_{n \rightarrow \infty} d(W(x_n, Lx_n, \tau_n), \rho) &= \limsup_{n \rightarrow \infty} d(z_n, \rho) \\ &\leq \lim_{n \rightarrow \infty} \sup d(x_n, \rho) = \varphi \dots (8) \end{aligned}$$

$$\begin{aligned} \limsup_{n \rightarrow \infty} d(W(Lx_n, Lz_n, \mu_n), \rho) &= \limsup_{n \rightarrow \infty} d(y_n, \rho) \\ &\leq \lim_{n \rightarrow \infty} \sup d(x_n, \rho) = \varphi \dots (9) \end{aligned}$$

From condition (2), (3) and (4), we get

$$\begin{aligned} d(x_{n+1}, \rho) &= d(W(Ly_n), \rho) \\ &\leq d(Ly_n, \rho) \\ &\leq d(y_n, \rho) \\ &= d(W(Lx_n, Lz_n, \mu_n), \rho) \\ &\leq (1 - \mu_n)d(Lx_n, \rho) + \mu_n d(Lz_n, \rho) \\ &\leq (1 - \mu_n)d(x_n, \rho) + \mu_n d(z_n, \rho) \\ &\leq d(x_n, \rho) - \mu_n d(x_n, \rho) + \mu_n d(z_n, \rho) \end{aligned}$$



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This implies that

$$\frac{d(x_{n+1}, \rho) - d(x_n, \rho)}{\mu_n} \leq d(z_n, \rho) - d(x_n, \rho)$$

So

$$\begin{aligned} d(x_{n+1}, \rho) - d(x_n, \rho) &\leq \frac{d(x_{n+1}, \rho) - d(x_n, \rho)}{\mu_n} \\ &\leq d(z_n, \rho) - d(x_n, \rho) \end{aligned}$$

Then  $d(x_{n+1}, \rho) \leq d(z_n, \rho)$

Therefore

$$\varphi \leq \lim_{n \rightarrow \infty} \inf d(z_n, \rho) . \quad \dots(10)$$

From condition (8) and (10) , we get

$$\begin{aligned} \varphi &= \lim_{n \rightarrow \infty} d(z_n, \rho) \\ \varphi &= \lim_{n \rightarrow \infty} d(W(x_n, Lx_n, \tau_n), \rho) . \quad \dots(11) \end{aligned}$$

From condition (7) , (9), (11) and lemma (2.5), we get

$$\lim_{n \rightarrow \infty} d(Lx_n, x_n) = 0.$$

### Theorem(3.3)

Let  $B, A, L$  and  $\{x_n\}$  be as in theorem(3.2) with  $F(L) \neq \emptyset$  if  $L$  satisfies condition (I), then  $\lim_{n \rightarrow \infty} \|x_n - \rho\| = 0, \rho \in F(L)$ .

Proof:

From theorem (3.1), implies that  $\lim_{n \rightarrow \infty} d(x_n, \rho)$  exists ,  $\forall \rho \in F(L)$



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and so  $\lim_{n \rightarrow \infty} d(x_n, F(L))$  exists . Assume that  $\lim_{n \rightarrow \infty} d(x_n, \rho) = \varphi$  for some  $\varphi > 0$ . From condition (I) ,  $F(L) \neq \emptyset$  and theorem(3.2), we get  $\lim_{n \rightarrow \infty} k(d(x, F(L))) \leq \lim_{n \rightarrow \infty} d(x_n, Lx_n) = 0$  implies that

$$\lim_{n \rightarrow \infty} k(d(x, F(L))) = 0 \quad \dots (12)$$

Since  $k$  is a nondecreasing function and from condition (12), we get

$\lim_{n \rightarrow \infty} (d(x, F(L))) = 0$  . Thus there are subsequences  $\{x_{n_t}\}$  of  $\{x_n\}$  and  $\{\rho_t\} \subset F$  such that  $d(x_{n_t}, \rho_t) < \frac{1}{2^t}$

From theorem (3.1) ,  $\forall t > 0$ , we get

$$d(x_{n_{t+1}}, \rho_t) \leq d(x_{n_t}, \rho_t) < \frac{1}{2^t}$$

Also , we get  $\{\rho_t\}$  is a Cauchy sequence in  $A$  and converges to  $\rho \in A$  by

$$\begin{aligned} d(\rho_{t+1}, \rho_t) &\leq d(\rho_{t+1}, x_{n_{t+1}}) + d(x_{n_{t+1}}, \rho_t) \\ &< \frac{1}{2^{t+1}} + \frac{1}{2^t} \\ &< \frac{1}{2^{t-1}} \end{aligned}$$

Since  $d(\rho_t, L\rho) \leq d(\rho, \rho_t)$  and  $\rho_t \rightarrow \rho$  as  $\tau \rightarrow \infty$  , it follows that  $d(\rho, L\rho) = 0$ , which implies that  $\rho \in L\rho$

### Theorem(3.4)

Let  $B, A, L$  and  $\{x_n\}$  be as in theorem (3.2) with  $F(L) \neq \emptyset$  if  $L$  is hemicompact , then  $\lim_{n \rightarrow \infty} \|x_n - \rho\| = 0, \rho \in F(L)$ .

proof : From theorem(3.2) , we get  $\lim_{n \rightarrow \infty} d(x_n, Lx_n) = 0$  and  $L$  is hemicompact , there is a subsequence  $\{x_{n_t}\}$  of  $\{x_n\}$  such that  $x_{n_t} \rightarrow \rho$  as  $\tau \rightarrow \infty$  for some  $\rho \in A$ . Since  $L$  is a nonexpansive mapping ,





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$$d(\rho, L\rho) \leq d(\rho, x_{n_t}) + d(x_{n_t}, Lx_{n_t}) + d(Lx_{n_t}, L\rho) \\ \leq 2d(x_{n_t}, \rho) + d(x_{n_t}, Lx_{n_t}) \rightarrow 0 \quad \text{as } \tau \rightarrow \infty .$$

this implies that  $\rho \in L\rho$  .

#### 4 – Conclusions

A Three – Step – One Mapping Iterative scheme for self mapping has been introduced in W-Hyperbolic and the convergence result for A Three – Step – One Mapping Iterative Scheme has been proved when used nonexpansive self mapping in Hyperbolic space also established the convergence results has been established in uniformly Hyperbolic space when use Condition (I) and use Hemicompact mapping .

#### 5 – Suggestion

1 – we can use Lipschizian mapping to established the convergence results .

2 – we can use another space to establish the convergence results of same iteration .

3 – we can use another iteration to established the convergence results .

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