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RESULTS ON GENERAL ϕ-WEAKLY RANDOM OPERATORS

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Abstract: In this paper, firstly, we prove the existence of random coincidence points for general ϕ-weakly contraction condition under two pairs of random operators, where ϕ is continuous monotone real function. As applications, related common fixed point results are established, the well-posed random fixed point problem is studied and the convergence of random Mann's iteration to a common random fixed point is proved. Our results, essentially, are cover special cases about existence random coincidence points.

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1. Introduction and Preliminaries

The stochastic generalization of coincidence points are random coincidence points. The study of random coincidence point was initiated to Beg and Shahzad [10] who proved important results about common random fixed points and random coincidence points for compatible random operators in Banach

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spaces, where compatibility is a generalization of commuting operators. Some random coincidence points for f- non-expansive operators are established using the commutativity condition by Latif and Tweddle [4]. And then, Shahzad and Latif [11] presented other random results of their work. Kumam and Plubtieng [15] proved the existence random coincidence points of compatible single and multivalued random operators and extended the results in [13]. Also, the random coincidence point results are proved in [17] for pair of commuting mapping defined on weakly compact separable subset of complete p-normed space. And then, use them to study the random best approximation in p-normed space with reparability condition. Recently, Gupta and Karapnar [2] introduced the notion of random coupled coincidence points and proved the existence of such points. In [9], Beg and et al. studied random coincidence for weakly compatible random operator which satisfy a weak contraction condition in convex metric spaces . Also, Jhadd and Salua [14] gave other results for multivalued random operator In this field, one can see also [19] and [23]. The aim of this article is to obtain random coincidence point theorem for two pairs of random operators that satisfy contraction condition which is substantially generalization to a condition (1) in [9] (regardless the back ground space X).

Let X be a linear space and $\|\|_p$ be a real valued function on X with $0 < p \leq 1$. The ordered pair $(X, \|\|_p)$ is called a p-normed space [15] if for all x, y in X and scalars λ:

i. $||x||_p \geq 0$ and $||x||_p = 0$ if and only if $x = 0$.

ii. $||\lambda x||_p = |\lambda|^p ||x||_p$.

iii. $||x + y||_p \leq ||x||_p + ||y||_p$.

for more details about p-normed spaces, see [1] or [3]. Throughout this article X will be separable complete p-normed space whose dual separates the points of it, $\phi \neq A \subseteq X$ be a closed, (Ω, Σ) be the measurable space with Σ a sigma algebra of subsets of Ω, 2^X is the classes of all subsets of X and $CB(X)$ is the classes of all non-empty bounded closed subsets of X.

Definition 1. [16] A mapping $F : \Omega \longrightarrow 2^X$ is called measurable (respectively, weakly measurable) if, for any closed(respectively, open) subset B of X,

$$F^{-1}(B) = \{\omega \in \Omega : F(\omega) \cap B \neq \emptyset\} \in \Sigma$$

Definition 2. [16] A mapping $\delta : \Omega \longrightarrow 2^X$ is called a measurable selector of a measurable mapping $F : \Omega \longrightarrow 2^X$ if δ measurable and $\delta(\omega) \in F(\omega)$ for each $\omega \in \Omega$.

Definition 3. [14] A mapping $h : \Omega \times X \longrightarrow X$ (or $G : \Omega \times X \longrightarrow CB(X)$) is called a random operator if for any $x \in X$,$h(., x)$(respectively $G(., x)$) is measurable.

Definition 4. [11] A measurable mapping $\delta : \Omega \longrightarrow A$ is called random fixed point of a random operator $h : \Omega \times X \longrightarrow X$ (or $G : \Omega \times X \longrightarrow CB(X)$ if for every $\omega \in \Omega, \delta(\omega) = h(\omega, \delta(\omega))$ (respectively $\delta(\omega) \in G(\omega, \delta(\omega))$).

Definition 5. [9] A measurable mapping $\delta : \Omega \longrightarrow A$ is called random coincidence point of a random operator $h : \Omega \times A \longrightarrow A$ and $G : \Omega \times A \longrightarrow A$ if for every $\omega \in \Omega, , h(\omega, \delta(\omega)) = G(\omega, \delta(\omega))$.

Definition 6. [9] A measurable mapping $\delta : \Omega \longrightarrow A$ is called common random fixed point of a random operator $h : \Omega \times A \longrightarrow X$ and $G : \Omega \times A \longrightarrow A$ if for every $\omega \in \Omega$

$$\delta(\omega) = h(\omega, \delta(\omega)) = G(\omega, \delta(\omega))$$

Definition 7. [12] A random operator $h : \Omega \times A \longrightarrow X$ is called continuous (weakly continuous) if for each $\omega \in \Omega, h(\omega, .)$ is continuous (weakly continuous).

Now, we define a new type of random operators.

Definition 8. Let $h, G, S, T : \Omega \times X \longrightarrow X$ be four random operators. (h, G, ϕ) is called generalized weakly contractive with respect to the pair (S, T)if for all $x, y \in X$,

$$\|S(\omega, x) - T(\omega, y)\|_p \leq M(x, y) - \phi(M(x, y)) \tag{1}$$

where:

$$M(x, y) = \max\Big\{\|h(\omega, x) - G(\omega, y)\|_p, \|h(\omega, x) - S(\omega, x)\|_p,$$

$$\|G(\omega, y) - T(\omega, y)\|_p, \frac{1}{2}\Big[\|h(\omega, x) - T(\omega, y)\|_p + \|G(\omega, y) - h(\omega, x)\|_p\Big]\Big\}$$

for each $x, y \in \Omega$, where $\phi : [0, \infty) \longrightarrow [0, \infty)$ is continuous and nondecreasing map such that, $\phi(0) = 0$ and $\lim_{t\to\infty} \phi(t) = \infty$.

As special case is:

Definition 9. Let $h, S : \Omega \times X \longrightarrow X$ be two random operators. Then (h, ϕ) is called weakly contractive with respect to S if for all $x, y \in X$,

$$\|S(\omega, x) - S(\omega, y)\|_p \leq \|h(\omega, x) - h(\omega, y)\|_p - \phi\left(\|h(\omega, x) - h(\omega, y)\|_p\right) \tag{2}$$

for each $x, y \in \Omega$, where $\phi : [0, \infty) \longrightarrow [0, \infty)$ is continuous and nondecreasing map such that, $\phi(0) = 0$ and $\lim_{t\to\infty} \phi(t) = \infty$.

Definition 10. [7] Let $h, G : X \longrightarrow X$ be two mappings, then h and G are called R-weakly commuting if for all $x \in X$ there exists $R > 0$, such that:

$$\|Ghx - hGx\|_p \leq R\,\|Gx - hx\|_p$$

Definition 11. [8] A pair (h, G) of self mappings of X is said to be weakly compatible, if they commute at their coincidence points, i.e., $hGx = Ghx$ for all x satisfying $h(x) = G(x)$.

The following definition appeared in [7] and [8] respectively:

Definition 12. A random operators $h, G : \Omega \times X \longrightarrow X$ are said to be R-weakly commute (or Weakly Compatible) if $h(\omega, .)$ and $G(\omega, .)$ are R-weakly commute (respectively weakly compatible) for each $\omega \in \Omega$.

2. Random Coincidence Theorems

We prove that:

Theorem 13. *Let $h, G, S, T : \Omega \times A \longrightarrow A$ be random operators and the pairs(S, T) and (h, G) satisfy condition (1). If for each $\omega \in \Omega$, $S(\omega, A) \subseteq G(\omega, A)$, $T(\omega, A) \subseteq h(\omega, A)$ and one of the subset $S(\omega, A)$, $h(\omega, A)$, $T(\omega, A)$ or $G(\omega, A)$ is a separable complete subspace of A. Then: i. The pair S, h has random coincidence point; ii. The pair T, G has random coincidence point.*

Proof. Let $\delta_0 : \Omega \longrightarrow A$ be arbitrary measurable mapping. Set $y_0 = S(\omega, \delta_0(\omega))$. We construct a sequence of measurable mappings $\delta_n : \Omega \longrightarrow A$ as the following: Since $S(\omega, A) \subseteq G(\omega, A)$, then we can find $\delta_1 : \Omega \longrightarrow A$, such that $y_0 = S(\omega, \delta_0(\omega)) = G(\omega, \delta_1(\omega))$. Set $y_1 = T(\omega, \delta_1(\omega))$. Since $T(\omega, A) \subseteq h(\omega, A)$, then there exists $\delta_2 : \Omega \longrightarrow A$, such that $h(\omega, \delta_2(\omega)) = T(\omega, \delta_1(\omega)) = y_1$. By induction, we have two sequences $\{y_n\}$ and $\{\delta_n\}$ in A, such that for all nonnegative integer

$$y_{2n} = S(\omega, \delta_{2n}(\omega)) = G(\omega, \delta_{2n+1}(\omega)) \tag{3}$$

and

$$y_{2n+1} = h(\omega, \delta_{2n+2}(\omega)) = T(\omega, \delta_{2n+1}(\omega)) \tag{4}$$

From (3), (4) and (1), we have:

$$\begin{aligned}
\|y_{2n+2} - y_{2n+1}\|_p &= \|S(\omega, \delta_{2n+2}(\omega)) - T(\omega, \delta_{2n+1}(\omega))\|_p \\
&\leq M(\delta_{2n+2}(\omega), \delta_{2n+1}(\omega)) - \phi(M(\delta_{2n+2}(\omega), \delta_{2n+1}(\omega)) \\
&= \max\Big\{\|h(\omega, \delta_{2n+2}(\omega)) - G(\omega, \delta_{2n+1}(\omega))\|_p, \|h(\omega, \delta_{2n+2}(\omega)) - \\
&S(\omega, \delta_{2n+2}(\omega))\|_p, \|G(\omega, \delta_{2n+1}(\omega)) - T(\omega, \delta_{2n+1}(\omega))\|_p, \\
&\tfrac{1}{2}\Big[\|h(\omega, \delta_{2n+2}(\omega)) - T(\omega, \delta_{2n+1}(\omega))\|_p + \|G(\omega, \delta_{2n+1}(\omega)) - \\
&S(\omega, \delta_{2n+2}(\omega))\|_p\Big]\Big\} - \phi\Big(\Big\{\|h(\omega, \delta_{2n+2}(\omega)) - G(\omega, \delta_{2n+1}(\omega))\|_p, \\
&\|h(\omega, \delta_{2n+2}(\omega)) - S(\omega, \delta_{2n+2}(\omega))\|_p, \|G(\omega, \delta_{2n+1}(\omega)) - \\
&T(\omega, \delta_{2n+1}(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega, \delta_{2n+2}(\omega)) - T(\omega, \delta_{2n+1}(\omega))\|_p + \\
&\|G(\omega, \delta_{2n+1}(\omega)) - S(\omega, \delta_{2n+2}(\omega))\|_p\Big]\Big\}\Big) \\
&= \max\Big\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p, \|y_{2n} - y_{2n+1}\|_p, \\
&\tfrac{1}{2}\Big[\|y_{2n+1} - y_{2n+1}\|_p + \|y_{2n} - y_{2n+2}\|_p\Big]\Big\} - \\
&\phi\Big(\max\Big\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p, \|y_{2n} - y_{2n+1}\|_p, \\
&\tfrac{1}{2}\Big[\|y_{2n+1} - y_{2n+1}\|_p + \|y_{2n} - y_{2n+2}\|_p\Big]\Big\}\Big) \\
&= \max\Big\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p, \tfrac{1}{2}\|y_{2n} - y_{2n+2}\|_p\Big\} - \\
&\phi\Big(\max\Big\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p, \tfrac{1}{2}\|y_{2n} - y_{2n+2}\|_p\Big\}\Big)
\end{aligned} \tag{5}$$

Using triangle inequality, property $\frac{1}{2}[a+b] \leq max\{a, b\}$ and property of ϕ, we get:

$$\begin{aligned}
\|y_{2n+2} - y_{2n+1}\|_p &\leq \max\Big\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p, \tfrac{1}{2}[\|y_{2n} - \\
&y_{2n+1}\|_p + \|y_{2n+1} - y_{2n+2}\|_p\Big] - \phi\Big(\max\Big\{\|y_{2n+1} - y_{2n}\|_p, \\
&\|y_{2n+1} - y_{2n+2}\|_p, \tfrac{1}{2}\Big[\|y_{2n} - y_{2n+1}\|_p + \|y_{2n+1} - y_{2n+2}\|_p\Big]\Big\}\Big) \\
&\leq \max\Big\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p\Big\} - \phi\,(\max\{\|y_{2n+1} - \\
&y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p\Big\}
\end{aligned} \tag{6}$$

If $\max\left\{\|y_{2n+1} - y_{2n}\|_p, \|y_{2n+1} - y_{2n+2}\|_p\right\} = \|y_{2n+1} - y_{2n+2}\|_p$, then by (6), we have

$$\begin{aligned}
0 < \|y_{2n+1} - y_{2n+2}\|_p &\leq \|y_{2n+1} - y_{2n+2}\|_p - \phi\Big(\|y_{2n+1} - y_{2n+2}\|_p\Big) \\
&< \|y_{2n+1} - y_{2n}\|_p\ ,
\end{aligned}$$

which is a contradiction. Thus,
$\max\left\{\|y_{2n+1}-y_{2n}\|_p, \|y_{2n+1}-y_{2n+2}\|_p\right\} = \|y_{2n+1}-y_{2n}\|_p$. This implies,

$$\begin{aligned}\|y_{2n+1}-y_{2n+2}\|_p &\leq \|y_{2n+1}-y_{2n}\|_p - \phi\big(\|y_{2n+1}-y_{2n}\|_p\big)\\ &\leq \|y_{2n+1}-y_{2n}\|_p.\end{aligned}$$

Hence for all nonnegative integer n, we have:

$$\left\|y_{2n+1}-y_{2n+2}\right\|_p \leq \left\|y_{2n+1}-y_{2n}\right\|_p$$

thus sequence $\left\{\left\|y_{2n+1}-y_{2n+2}\right\|_p\right\}$ is non-increasing of positive real numbers. Hence, it converges to $r \geq 0$. If $r > 0$, then:

$$\left\|y_n-y_{n+1}\right\|_p \leq \left\|y_{n-1}-y_n\right\|_p - \phi\left(\left\|y_{n-1}-y_n\right\|_p\right)$$

$r \leq r-\theta(r) < r$, which is contradiction. Hence $r = 0$ and

$$\lim_{n\to\infty}\left\|y_{n+1}-y_n\right\|_p = 0 \tag{7}$$

Now, we show $\{y_n\}$ is a Cauchy sequence. Since $\lim_{n\to\infty}\left\|y_{n+1}-y_n\right\|_p = 0$, then we need only to show that $\{y_{2n}\}$ is a Cauchy sequence. Suppose that this is not the case, then there exists $\varepsilon > 0$ and there exists even integers $2n(k)$ and $2m(k)$ with $2k \leq 2m(k) < 2n(k)$, such that:

$$\left\|y_{2m(k)}-y_{2n(k)}\right\|_p > \varepsilon \textit{ and } \left\|y_{2n(k)-2}-y_{2m(k)}\right\|_p \leq \varepsilon$$

Using (7) following inequality, we have:

$$\varepsilon < \left\|y_{2m(k)}-y_{2n(k)}\right\|_p \leq \left\|y_{2m(k)}-y_{2n(k)-2}\right\|_p + \left\|y_{2m(k)-2}-y_{2n(k)-1}\right\|_p + \left\|y_{2m(k)-1}-y_{2n(k)}\right\|_p$$

hence $\varepsilon < \lim_{k\to\infty}\left\|y_{2m(k)}-y_{2n(k)}\right\|_p \leq \varepsilon + 0 + 0$. Therefore:

$$\lim_{k\to\infty}\left\|y_{2m(k)}-y_{2n(k)}\right\|_p = \varepsilon \tag{8}$$

Also (7), (8) following inequality, we have:

$$\left\|y_{2m(k)}-y_{2n(k)}\right\|_p \leq \left\|y_{2m(k)}-y_{2m(k)+1}\right\|_p + \left\|y_{2m(k)+1}-y_{2n(k)}\right\|_p$$

Then:

$$\lim_{k\to\infty}\left\|y_{2m(k)}-y_{2n(k)}\right\|_p \leq \lim_{k\to\infty}\left\|y_{2m(k)}-y_{2m(k)+1}\right\|_p + \lim_{k\to\infty}\left\|y_{2m(k)+1}-y_{2n(k)}\right\|_p$$

$$\leq 0 + \lim_{k\to\infty} \left\|y_{2m(k)+1} - y_{2n(k)}\right\|_p$$

while (5), (7) and inequality:

$$\left\|y_{2m(k)+1} - y_{2n(k)}\right\|_p \leq \left\|y_{2m(k)+1} - y_{2n(k)}\right\|_p + \left\|y_{2m(k)} - y_{2n(k)}\right\|_p$$

$$\lim_{k\to\infty} \left\|y_{2m(k)+1} - y_{2n(k)}\right\|_p \leq 0 + \varepsilon$$

Hence, $\lim_{k\to\infty} \left\|y_{2m(k)+1} - y_{2n(k)}\right\|_p \leq 0 + \varepsilon$, and this implies:

$$\lim_{k\to\infty} \left\|y_{2m(k)+1} - y_{2n(k)}\right\|_p = \varepsilon \tag{9}$$

By the similar way, we have:

$$\lim_{k\to\infty} \left\|y_{2m(k)} - y_{2n(k)-1}\right\|_p = \lim_{k\to\infty} \left\|y_{2n(k)-1} - y_{2n(k)+1}\right\|_p = \varepsilon \tag{10}$$

for all nonnegative integer k, (1) implies that:

$$\begin{aligned}
\left\|y_{2n(k)} - y_{2m(k)+1}\right\|_p &= \left\|S(\omega, y_{2n(k)}) - T(\omega, y_{2m(k)+1})\right\|_p \\
&\leq M(y_{2n(k)}, y_{2m(k)+1}) - \phi(My_{2n(k)}, y_{2m(k)+1}) \\
&\leq \left\|y_{2n(k)-1} - y_{2m(k)}\right\|_p - \phi\left(\left\|y_{2n(k)-1} - y_{2m(k)}\right\|_p\right)
\end{aligned}$$

$$\lim_{k\to\infty} \left\|y_{2n(k)} - y_{2m(k)+1}\right\|_p \leq \lim_{k\to\infty} \left\|y_{2n(k)-1} - y_{2m(k)}\right\|_p - \lim_{k\to\infty} \phi\left(\left\|y_{2n(k)-1} - y_{2m(k)}\right\|_p\right)$$

Also, (9) and (10), implies that $\varepsilon \leq \varepsilon - \phi(\varepsilon)$, which is contradiction with $\varepsilon > 0$, hence $\{y_{2n}\}$ is a Cauchy sequence. Suppose that $G(\omega, A)$ is a complete subspace of , this implies the sequence $\{y_n\}$ has a limit $t : \Omega \longrightarrow G(A)$. We obtained a mapping $u : \Omega \longrightarrow A$, such that $(\omega, u(\omega)) = t(\omega)$. So:

$$t(\omega) = \lim_{n\to\infty} y_{2n} = \lim_{n\to\infty} S(\omega, \delta_{2n}(\omega)) = \lim_{n\to\infty} G(\omega, \delta_{2n+1}(\omega))$$

and

$$\begin{aligned}
t(\omega) = \lim_{n\to\infty} y_{2n+1} &= \lim_{n\to\infty} h(\omega, \delta_{2n+2}(\omega)) = \lim_{n\to\infty} T(\omega, \delta_{2n+1}(\omega)) \\
&= \lim_{n\to\infty} G(\omega, \delta_{2n+1}(\omega))
\end{aligned}$$

Using (3) and (1), we have:

$$\|y_{2n} - T(\omega, u(\omega))\|_p = \|S(\omega, \delta_{2n}(\omega)) - T(\omega, u(\omega))\|_p$$
$$\leq \max\Big\{\|h(\omega, \delta_{2n}(\omega)) - G(\omega, u(\omega))\|_p, \|h(\omega, \delta_{2n}(\omega)) - S(\omega, \delta_{2n}(\omega))\|_p,$$
$$\|G(\omega, u(\omega)) - T(\omega, u(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega, \delta_{2n}(\omega)) - T(\omega, u(\omega))\|_p +$$
$$\|G(\omega, u(\omega)) - S(\omega, \delta_{2n}(\omega))\|_p\Big]\Big\} - \phi\left(\max\{\|h(\omega, \delta_{2n}(\omega)) -\right.$$
$$G(\omega, u(\omega))\|_p, \|h(\omega, \delta_{2n}(\omega)) - \delta_{2n}(\omega, u(\omega))\|_p, \|G(\omega, u(\omega)) -$$
$$T(\omega, u(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega, \delta_{2n}(\omega)) - T(\omega, u(\omega))\|_p + \|G(\omega, u(\omega)) -$$
$$\left. S(\omega, \delta_{2n}(\omega))\|_p\Big]\Big\}\right)$$

taking limit as $n \longrightarrow \infty$, we get:

$$\|t(\omega) - T(\omega, u(\omega))\|_p \leq \max\Big\{\|t(\omega) - T(\omega, u(\omega))\|_p, \tfrac{1}{2}\|t(\omega) -$$
$$T(\omega, u(\omega))\|_p\Big\} - \phi\Big(\max\Big\{\|G(\omega, u(\omega)) - T(\omega, u(\omega))\|_p, \tfrac{1}{2}\|t(\omega) -$$
$$T(\omega, u(\omega))\|_p\Big\}\Big)$$
$$= \|t(\omega) - T(\omega, u(\omega))\|_p - \phi\left(\|t(\omega) - T(\omega, u(\omega))\|_p\right)$$

by properties of ϕ, obtaining $\phi\left(\|t(\omega) - T(\omega, u(\omega))\|_p\right) = 0$, this implies

$$\|t(\omega) - T(\omega, u(\omega))\|_p = 0,$$

and hence:

$$t(\omega) = T(\omega, u(\omega)) = G(\omega, u(\omega)) \tag{11}$$

Since $(\omega, A) \subseteq h(\omega, A)$, then $t(\omega) \in h(\omega, A)$, a mapping $v : \Omega \longrightarrow A$, exists, such that:

$$h(\omega, v(\omega)) = t(\omega) \tag{12}$$

By (11), (1) and (12),we have:

$$\|S(\omega, v(\omega)) - t(\omega)\|_p = \|S(\omega, v(\omega)) - T(\omega, u(\omega))\|_p$$

$$\leq \max\Big\{\|h(\omega,v(\omega))-G(\omega,u(\omega))\|_p, \|h(\omega,v(\omega))-S(\omega,v(\omega))\|_p, \|G(\omega,u(\omega))-T(\omega,u(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,v(\omega))-T(\omega,u(\omega))\|_p + \|G(\omega,u(\omega))-S(\omega,v(\omega))\|_p\Big]\Big\} - \phi\Big(\max\Big\{\|h(\omega,v(\omega))- G(\omega,u(\omega))\|_p, \|h(\omega,v(\omega))-S(\omega,v(\omega))\|_p, \|G(\omega,u(\omega))- T(\omega,u(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,v(\omega))-T(\omega,u(\omega))\|_p + \|G(\omega,u(\omega))-S(\omega,v(\omega))\|_p\Big]\Big\}\Big)$$

$$= \max\Big\{\|t(\omega)-S(\omega,v(\omega))\|_p, \tfrac{1}{2}\|t(\omega)-S(\omega,v(\omega))\|_p\Big\} - \phi\Big(\max\Big\{\|t(\omega)-S(\omega,v(\omega))\|_p, \tfrac{1}{2}\|t(\omega)-S(\omega,v(\omega))\|_p\Big\}\Big)$$

$$= \|t(\omega)-S(\omega,v(\omega))\|_p - \phi\Big(\|t(\omega)-S(\omega,v(\omega))\|_p\Big)$$

so we get $\phi\Big(\|t(\omega)-S(\omega,v(\omega))\|_p\Big) = 0$. This implies $\|t(\omega)-S(\omega,v(\omega))\|_p = 0$ Therefore, $h(\omega,v(\omega)) = h(\omega,v(\omega)) = t(\omega)$ Hence $v : \Omega \longrightarrow A$ is a random coincidence point of hand S Finally, we have:

$$h(\omega,v(\omega)) = h(\omega,v(\omega)) = t(\omega) = T(\omega,u(\omega)) = G(\omega,u(\omega)) \tag{13}$$

Theorem 14. *Let $S,T,h,G : \Omega\times A \longrightarrow A$ satisfying inequality (1). If the pairs $\{S,h\}$ and $\{T,G\}$ are weakly compatible (R-weakly commuting), $S(\omega,A)\subseteq G(\omega,A)$, $T(\omega,A)\subseteq h(\omega,A)$ and one of the subsets $S(\omega,A)$, $h(\omega,A)$, $T(\omega,A)$ or $G(\omega,A)$ is a separable complete subspace of A, then S, h, T and G have a unique common random fixed point.*

Proof. By theorem (13), there exists random coincidence point $u:\Omega\longrightarrow A$ of G and T, such that $T(\omega,u(\omega)) = G(\omega,u(\omega))$ and random coincidence point of G and S, such that $h(\omega,v(\omega)) = S(\omega,v(\omega))$. If the pairs $\{S,h\}$ and $\{T,G\}$ are weakly compatible, then:

$$S(\omega, h(\omega,v(\omega))) = h(\omega, S(\omega,v(\omega)))$$

and

$$T(\omega, G(\omega,u(\omega))) = G(\omega, T(\omega,u(\omega)))$$

from (13), we have:

$$S(\omega,t(\omega)) = h(\omega,t(\omega)) \textit{ and } T(\omega,t(\omega)) = G(\omega,t(\omega)) \tag{14}$$

from (13), (1) and (14), we have:

$$\begin{aligned}\|t(\omega)-T(\omega,t(\omega))\|_p &= \|S(\omega,v(\omega))-T(\omega,t(\omega))\|_p \\ &\le \max\Big\{\|h(\omega,v(\omega))-G(\omega,t(\omega))\|_p, \|h(\omega,v(\omega))-S(\omega,t(\omega))\|_p, \\ &\|G(\omega,t(\omega))-T(\omega,t(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,v(\omega))-T(\omega,t(\omega))\|_p + \\ &\|G(\omega,t(\omega))-S(\omega,v(\omega))\|_p\Big]\Big\} - \phi(\max\{\|h(\omega,v(\omega))- \\ &G(\omega,t(\omega))\|_p, \|h(\omega,v(\omega))-S(\omega,v(\omega))\|_p, \|G(\omega,t(\omega))- \\ &T(\omega,t(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,v(\omega))-T(\omega,t(\omega))\|_p + \|G(\omega,t(\omega))- \\ &S(\omega,v(\omega))\|_p\Big]\Big\}\Big) \\ &= \|t(\omega)-T(\omega,t(\omega))\|_p - \phi\Big(\|t(\omega)-T(\omega,t(\omega))\|_p\Big)\end{aligned}$$

This implies $\phi\Big(\|t(\omega)-T(\omega,t(\omega))\|_p\Big) = 0$. Thus by properties of ϕ, we have $\|t(\omega)-T(\omega,t(\omega))\|_p = 0$. Therefore $t(\omega) = T(\omega,t(\omega))$. From (14), we have:

$$t(\omega) = T(\omega,t(\omega)) = G(\omega,t(\omega)) \tag{15}$$

Again, from (15), (1) and (14), we get:

$$\begin{aligned}\|S(\omega,t(\omega))-t(\omega)\|_p &= \|S(\omega,t(\omega))-T(\omega,t(\omega))\|_p \\ &\le \max\Big\{\|h(\omega,t(\omega))-G(\omega,t(\omega))\|_p, \|h(\omega,t(\omega))-S(\omega,t(\omega))\|_p, \\ &\|G(\omega,t(\omega))-T(\omega,t(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,t(\omega))-T(\omega,t(\omega))\|_p + \\ &\|G(\omega,t(\omega))-S(\omega,t(\omega))\|_p\Big]\Big\} - \phi(\max\{\|h(\omega,t(\omega))- \\ &G(\omega,t(\omega))\|_p, \|h(\omega,t(\omega))-S(\omega,t(\omega))\|_p, \|G(\omega,t(\omega))- \\ &T(\omega,t(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,t(\omega))-T(\omega,t(\omega))\|_p + \\ &\|G(\omega,t(\omega))-S(\omega,t(\omega))\|_p\Big]\Big\}\Big)\end{aligned}$$

$$= \|S(\omega,t(\omega)) - t(\omega)\|_p - \phi\left(\|S(\omega,t(\omega)) - t(\omega)\|_p\right)$$

Hence $\phi\left(\|S(\omega,t(\omega)) - t(\omega)\|_p\right) = 0$, then by property of ϕ and (14), we have:

$$S(\omega,t(\omega)) = t(\omega) = h(\omega,t(\omega)) \tag{16}$$

Since $T(\omega,t(\omega)) = G(\omega,t(\omega)) = t(\omega)$, then:

$$S(\omega,t(\omega)) = h(\omega,t(\omega)) = T(\omega,t(\omega)) = G(\omega,t(\omega)) = t(\omega) \tag{17}$$

Thus $t : \Omega \longrightarrow G(A)$ is a common random fixed point of S, T, h and G.

Uniqueness: Let $\alpha(\omega)$ be another common random fixed point of S, T, h and G, then by using (1), we have:

$$\begin{aligned}
\|t(\omega) - \alpha(\omega)\|_p &= \|S(\omega,t(\omega)) - T(\omega,\alpha(\omega))\|_p \\
&\leq \max\Big\{\|h(\omega,t(\omega)) - G(\omega,\alpha(\omega))\|_p, \|h(\omega,t(\omega)) - S(\omega,t(\omega))\|_p, \\
&\|G(\omega,\alpha(\omega)) - T(\omega,\alpha(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,t(\omega)) - T(\omega,\alpha(\omega))\|_p + \\
&\|G(\omega,\alpha(\omega)) - S(\omega,t(\omega))\|_p\Big]\Big\} - \phi\left(\max\{\|h(\omega,t(\omega)) - \right. \\
&G(\omega,\alpha(\omega))\|_p, \|h(\omega,t(\omega)) - S(\omega,t(\omega))\|_p, \|G(\omega,\alpha(\omega)) - \\
&T(\omega,\alpha(\omega))\|_p, \tfrac{1}{2}\Big[\|h(\omega,t(\omega)) - T(\omega,\alpha(\omega))\|_p + \\
&\left.\|G(\omega,\alpha(\omega)) - S(\omega,t(\omega))\|_p\}\Big]\right) \\
&= \|t(\omega) - \alpha(\omega)\|_p - \phi\left(\|t(\omega) - \alpha(\omega)\|_p\right)
\end{aligned}$$

Which gives $\phi\left(\|t(\omega) - \alpha(\omega)\|_p\right) = 0$, hence by properties of ϕ, we have

$$\|t(\omega) - \alpha(\omega)\|_p = 0,$$

which implies to $t(\omega) = \alpha(\omega)$ Assume that $\{S,h\}$ is R-weakly commuting and $v : \Omega \longrightarrow A$ is a random coincidence point of S and h, it follows that:

$$\|S(\omega,h(\omega,v(\omega))) - h(\omega,S(\omega,v(\omega)))\|_p \leq R\,\|G(\omega,v(\omega)) - h(\omega,v(\omega))\|_p = 0$$

Then $S(\omega,h(\omega,v(\omega))) - h(\omega,S(\omega,v(\omega))) = 0$, and thus $S(\omega,h(\omega,v(\omega))) = h(\omega,S(\omega,v(\omega)))$ Hence the pair $\{S,G\}$ is weakly compatible.

Similarly, we have $\{T, h\}$ is weakly compatible, then the same steps above we can show that $t : \Omega \longrightarrow h(A)$ is a unique common random fixed point of S, T, h and G.

As a consequence, we get the following:

Corollary 15. *Let $S, h : \Omega \times A \longrightarrow A$ and for all $x, y \in A$*

$$\|S(\omega,x) - S(\omega,y)\|_p \leq \max\Big\{\|h(\omega,x) - h(\omega,y)\|_p, \|h(\omega,x) - S(\omega,x)\|_p,$$

$$\|h(\omega,y) - S(\omega,y)\|_p, \tfrac{1}{2}\Big[\|h(\omega,x) - S(\omega,y)\|_p +$$

$$\|h(\omega,y) - S(\omega,x)\|_p\Big]\Big\} - \phi\Big(\max\Big(\|h(\omega,x) - h(\omega,y)\|_p,$$

$$\|h(\omega,x) - S(\omega,x)\|_p, \|h(\omega,y) - S(\omega,y)\|_p$$

$$\frac{1}{2}\Big[\|h(\omega,x) - S(\omega,y)\|_p + \|h(\omega,y) - S(\omega,x)\|_p\Big] \tag{18}$$

If $S(\omega, A) \in h(\omega, A)$ and one of the subset $S(\omega, A)$ or $h(\omega, A)$ is a separable complete p-normed subspace of A. Then the pair $\{S, h\}$ has random coincidence point.

Corollary 16. *Let $S, h : \Omega \times A \longrightarrow A$ satisfying inequality (19). If the pair $\{S, h\}$ is weakly compatible (R-weakly commuting), $S(\omega, A) \in h(\omega, A)$ and one of the subset $S(\omega, A)$ or $h(\omega, A)$is a separable complete p-normed subspace of A, then the pair $\{S, h\}$ has unique common random fixed point.*

Corollary 17. *Let $S, h : \Omega \times A \longrightarrow A$, such that h is ϕ-weakly contractive with respect to S. If $S(\omega, A) \in h(\omega, A)$ and one of the subset $S(\omega, A)$ or $h(\omega, A)$is a separable complete p-normed subspace of . Then the pair $\{S, h\}$ has random coincidence point.*

Corollary 18. *Let $S, h : \Omega \times A \longrightarrow A$, such that h is ϕ-weakly contractive with respect to S. If the pair $\{S, h\}$ is weakly compatible (R-weakly commuting), $S(\omega, A) \in h(\omega, A)$ and one of the subset $S(\omega, A)$ or $h(\omega, A)$ is a separable complete p-normed subspace of , then the pair $\{S, h\}$ has unique common random fixed point.*

Here, we must refer to analogous result appeared recently in [20] and [21].

3. Random Iteration Theorem

We define the following:

Definition 19. Let $h, S : \Omega \times X \longrightarrow X$ be two random operators, such that h is ϕ-weakly contractive with respect to S on a separable complete p-normed space X, and $S(\omega, X) \in h(\omega, X)$ with $h(\omega, X)$ convex subset of X, a sequence:

$$y_n = h(\omega, x_{n+1}) = (1 - \alpha_n(\omega))h(\omega, x_n) + \alpha_n S(\omega, x_n),\ x \in X,\ n \geq 0$$

where $\alpha_n : \Omega \longrightarrow [0, 1]$ for each $n \in N$ is called random Mann iterative scheme.

Theorem 20. *Let $S, h : \Omega \times A \longrightarrow A$, such that h is ϕ-weakly contractive with respect to S. If the pair $\{S, h\}$ is weakly compatible or R-weakly commuting and $(\omega, A) \in h(\omega, A)$, with $h(\omega, A)$ as a convex separable complete subspace of A, then random Mann iterative scheme with $\sum_{n=1}^{\infty} \alpha_n(\omega) = \infty$, converges to common random fixed point of S and h.*

Proof. By Corollary 18, S and h have a unique common random fixed point $: \Omega \longrightarrow h(\omega, A)$, such that:

$$h(\omega, t(\omega)) = S(\omega, t(\omega)) = t(\omega) \text{ and } t(\omega) = h(\omega, u(\omega)) = S(\omega, u(\omega))$$

Now, let $\{\delta_n(\omega)\}$ be the random Mann iterative scheme defined in Definition 19, then:

$$\begin{aligned}
\|\delta_n(\omega) - t(\omega)\|_p &= \|h(\omega, \delta_{n+1}(\omega)) - h(\omega, u(\omega))\|_p \\
&= \|(1 - \alpha_n(\omega))h(\omega, \delta_n(\omega)) + \alpha_n(\omega)S(\omega, \delta_n(\omega)) - h(\omega, u(\omega))\|_p \\
&= \|(1 - \alpha_n(\omega))h(\omega, \delta_n(\omega)) + \alpha_n(\omega)S(\omega, \delta_n(\omega)) - h(\omega, u(\omega)) + \\
&\quad \alpha_n(\omega)h(\omega, u(\omega)) - \alpha_n(\omega)h(\omega, u(\omega))\|_p \\
&= \|(1 - \alpha_n(\omega))(h(\omega, \delta_n(\omega)) - h(\omega, u(\omega))) + \alpha_n(\omega)S(\omega, \delta_n(\omega)) - \\
&\quad S(\omega, u(\omega))\|_p \\
&\leq |1 - \alpha_n(\omega)|^p \|h(\omega, \delta_n(\omega)) - h(\omega, u(\omega))\|_p + \\
&\quad |\alpha_n(\omega)|^p \|S(\omega, \delta_n(\omega)) - S(\omega, u(\omega))\|_p \\
&\leq (1 - \alpha_n(\omega)) \|h(\omega, \delta_n(\omega)) - h(\omega, u(\omega))\|_p +
\end{aligned}$$

$$\alpha_n(\omega)\left\|S(\omega,\delta_n(\omega))-S(\omega,u(\omega))\right\|_p$$

Since h is ϕ-weakly contractive with respect to S, then:

$$\left\|\delta_n(\omega)-t(\omega)\right\|_p \leq (1-\alpha_n(\omega))\left\|h(\omega,\delta_n(\omega))-h(\omega,u(\omega))\right\|_p+\alpha_n(\omega))\left\|h(\omega,\delta_n(\omega))-\right.$$

$$\left.h(\omega,u(\omega))\right\|_p-\alpha_n(\omega))\phi\left(\left\|h(\omega,\delta_n(\omega))-h(\omega,u(\omega))\right\|_p\right)$$

$$\leq (1-\alpha_n(\omega))\left\|h(\omega,\delta_n(\omega))-h(\omega,u(\omega))\right\|_p+$$
$$\alpha_n(\omega))\left\|h(\omega,\delta_n(\omega))-h(\omega,u(\omega))\right\|_p$$

Thus:

$$\left\|\delta_n(\omega)-t(\omega)\right\|_p \leq \left\|h(\omega,\delta_n(\omega))-h(\omega,u(\omega))\right\|_p=\left\|\delta_{n-1}(\omega)-t(\omega)\right\|_p$$

thus the sequence $\left\{\left\|\delta_n(\omega)-t(\omega)\right\|_p\right\}1$ is non-increasing of positive real numbers. Hence, it converges to $r \geq 0$. If > 0,then for any positive integer N, we have:

$$\sum_{n=N}^{\infty}\alpha_n(\omega)\phi(\omega,r) \leq \sum_{n=N}^{\infty}\alpha_n(\omega)\phi\left(\left\|\delta_n(\omega)-t(\omega)\right\|_p\right)$$

$$\leq \sum_{n=N}^{\infty}\left[\left\|\delta_n(\omega)-t(\omega)\right\|_p-\left\|\delta_{n+1}(\omega)-t(\omega)\right\|_p\right]$$

$$\leq \sum_{n=N}^{\infty}\left\|\delta_N(\omega)-t(\omega)\right\|_p$$

which contradicts $\sum_{n=1}^{\infty}\alpha_n(\omega)=\infty$, hence random Mann iterative scheme converges to common random fixed point of S and h.

4. Random Well-posed Problem

Several researchers have been study the well-posedness of a fixed point problem for single/multivalued mappings in the usual metric spaces, for examples [5], [6], [18], [23]. Hence we extend the notion of well-posedness to random fixed point problem.

Definition 21. Let $(X, \|\ \|_p)$ be a p-normed space and $T:\Omega\times X\longrightarrow X$ a random operator. The random fixed point problem of T is said to be well-posed if:
i. T has a unique random fixed point $\delta:\Omega\longrightarrow X$.

ii. For any sequence $\{\delta_n(\omega)\}$ of measurable mappings in X, such that:

$$\lim_{n\to\infty} \|T(\omega, \delta_n(\omega)) - \delta_n(\omega)\|_p = 0$$

we have:

$$\lim_{n\to\infty} \|\delta_n(\omega) - \delta(\omega)\|_p = 0$$

.

Definition 22. Let $(X, \| \|_p)$ be a p-normed space and let $\mathcal{T}$ be a set of a random operators in X. The random fixed point of $\mathcal{T}$is said to be well-posed if:
i. T has a unique random fixed point $\delta : \Omega \longrightarrow X$.
ii. For any sequence $\{\delta_n(\omega)\}$ of measurable mappings in X, such that:

$$\lim_{n\to\infty} \|T(\omega, \delta_n(\omega)) - \delta_n(\omega)\|_p = 0, \forall\ T \in \mathcal{T}$$

we have:

$$\lim_{n\to\infty} \|\delta_n(\omega) - \delta(\omega)\|_p = 0$$

.

Theorem 23. *Let X be a p-normed space and $\phi \neq A \subseteq X$ and S, T, h, G be a self random operators on A satisfying inequality (1). If the pairs $\{S, h\}$ and $\{G, T\}$ are weakly compatible or R-weakly commuting, $S(\omega, A) \subseteq G(\omega, A)$, $T(\omega, A) \subseteq h(\omega, A)$, for all $\omega \in \Omega$ and one of the subsets $S(\omega, A)$, $T(\omega, A)$, $G(\omega, A)$ or $h(\omega, A)$ is a separable complete subspace of A, then the common random fixed point for the set of random mappings $\{S, T, h, G\}$ is well-posed.*

Proof. By Theorem 20, the random mappings S, T, h and G have a unique common random fixed point $t : \Omega \longrightarrow A$. Let $\{\delta_n(\omega)\}$ be a sequence of measurable mappings in A, such that:

$$\begin{aligned}\lim_{n\to\infty} \|S(\omega, \delta_n(\omega)) - \delta_n(\omega)\|_p &= \lim_{n\to\infty} \|T(\omega, \delta_n(\omega)) - \delta_n(\omega)\|_p \\ &= \lim_{n\to\infty} \|h(\omega, \delta_n(\omega)) - \delta_n(\omega)\|_p \\ &= \lim_{n\to\infty} \|G(\omega, \delta_n(\omega)) - \delta_n(\omega)\|_p = 0\end{aligned}$$

For all nonnegative integer , we have:

$$M(t(\omega), \delta_n(\omega)) = \max\Big\{\|h(\omega, t(\omega)) - G(\omega, \delta_n(\omega))\|_p\,, \|h(\omega, t(\omega)) -$$

$$S(\omega,t(\omega))\|_p, \|G(\omega,\delta_n(\omega))-T(\omega,\delta_n(\omega))\|_p,$$
$$\|h(\omega,t(\omega))-T(\omega,\delta_n(\omega))\|_p+\|G(\omega,\delta_n(\omega))-$$
$$h(\omega,t(\omega))\|_p\Big]\Big\}$$

from (17), property $\frac{1}{2}(a+b)\leq\max\{a,b\}$ and using the triangle inequality, we get:

$$\begin{aligned}M(t(\omega),\delta_n(\omega)) &= \max\Big\{\|t(\omega)-G(\omega,\delta_n(\omega))\|_p, \|G(\omega,\delta_n(\omega))-\\ &\quad T(\omega,\delta_n(\omega))\|_p, \|t(\omega)-T(\omega,\delta_n(\omega))\|_p\Big]\Big\}\\ &\leq \max\Big\{\|t(\omega)-\delta_n(\omega)\|_p+\|\delta_n(\omega)-G(\omega,\delta_n(\omega))\|_p,\\ &\quad \|G(\omega,t(\omega))-t(\omega)\|_p+\|\delta_n(\omega)-T(\omega,\delta_n(\omega))\|_p,\\ &\quad \|h(\omega,t(\omega))-\delta_n(\omega)\|_p+\|\delta_n(\omega)-T(\omega,\delta_n(\omega))\|_p\Big\}\\ &\leq \|t(\omega)-\delta_n(\omega)\|_p+\|\delta_n(\omega)-G(\omega,\delta_n(\omega))\|_p+\\ &\qquad \|\delta_n(\omega)-T(\omega,\delta_n(\omega))\|_p \qquad (19)\end{aligned}$$

By the triangle inequality, (17), (1) and inequality (19), we have:

$$\begin{aligned}\|t(\omega)-\delta_n(\omega)\|_p &\leq \|t(\omega)-T(\omega,\delta_n(\omega))\|_p+\|T(\omega,\delta_n(\omega))-\delta_n(\omega)\|_p\\ &= \|S(\omega,t(\omega))-T(\omega,\delta_n(\omega))\|_p+\|T(\omega,\delta_n(\omega))-\delta_n(\omega)\|_p\end{aligned}$$

$$\phi\left(M(t(\omega),\delta_n(\omega))\right)\leq\|\delta_n(\omega)-G(\omega,\delta_n(\omega))\|_p+2\|\delta_n(\omega)-T(\omega,\delta_n(\omega))\|_p \quad (20)$$

Thus, we have:

$$\lim_{n\to\infty}\phi\left(M(t(\omega),\delta_n(\omega))\right)=0 \quad (21)$$

To get contradiction, let $\{\delta_n(\omega)\}$ does not converge to $t(\omega)$. Then there exists a positive number $\varepsilon>0$ and subsequence $\{\delta_m(\omega)\}$, such that:

$$\|t(\omega)-G(\omega,\delta_m(\omega))\|_p\geq\varepsilon, \text{ for all integer } m$$

Since ϕ is nondecreasing, from (20) and (21), we have:

$$\begin{aligned}\phi(\varepsilon) &\leq \phi\left(\|t(\omega) - G(\omega, \delta_m(\omega))\|_p\right)\\ &\leq \phi\left(M(t(\omega), G(\omega, \delta_m(\omega)))\right)\\ &\leq \phi\left(\|\delta_m(\omega) - G(\omega, (\omega))\|_p + 2\|\delta_m(\omega) - T(\omega, (\omega))\|_p\right)\end{aligned}$$

By letting $m \longrightarrow \infty$, we get $\phi(\varepsilon) = 0$, a contradiction to the property ϕ. Thus $\lim_{n\to\infty} \|\delta_n(\omega) - t(\omega)\|_p = 0$

Corollary 24. *Let $\emptyset \neq A$ separable complete subspace of X, and S and T be a self random mappings on A satisfying the following condition:*

$$\begin{aligned}\|S(\omega, x) - T(\omega, y)\|_p \leq \max\Big\{&\|x - y\|_p, \|x - S(\omega, x)\|_p, \|y - T(\omega, y)\|_p,\\ &\tfrac{1}{2}\left[\|x - T(\omega, y)\|_p + \|y - S(\omega, x)\|_p\right]\Big\} - \phi\Big(\max\Big\{\|x - y\|_p,\\ &\|x - S(\omega, x)\|_p, \|y - T(\omega, y)\|_p, \tfrac{1}{2}\left[\|x - T(\omega, y)\|_p +\right.\\ &\left.\|y - S(\omega, x)\|_p\right]\Big\}\Big)\end{aligned}$$

where $\phi : [0, \infty) \longrightarrow [0, \infty)$ is lower semi-continuous function with $\phi(t) > 0$, for all $t \in [0, \infty)$ and $\phi(0) = 0$. Then, there exists a unique common random fixed point $\delta : \Omega \longrightarrow A$ of S and T.
Moreover, if ϕ is nondecreasing function then the common random fixed point for the pair $\{S, T\}$ is well-posed.

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